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, Rivers—Regulation and improvement
, Estuaries

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THE

TRAINING OF RIVERS.

BY
LEVESON FRANCIS VERNON-HARCOURT,
M.A., M. Inst. C.E.;

AND

ESTUARIES.

BY
HENRI LÉON PARTIOT,
Inspecteur Général des Ponts et Chaussées.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPERS.

EDITED BY
JAMES FORREST, Assoc. Inst. C.E.,
SECRETARY.

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THE INSTITUTION OF CIVIL ENGINEERS.

SECT. I.—MINUTES OF PROCEEDINGS.

17 April, 1894.

SIR ROBERT RAWLINSON, K.C.B., Vice-President, in the Chair.

(*Paper No. 2767.*)

"The Training of Rivers, illustrated by the Results of various Training-Works."

By LEVESON FRANCIS VERNON-HARCOURT, M.A., M. Inst. C.E.

THE training of rivers may be carried out under four different conditions, namely, (1) above the tidal limit, or in tideless rivers above their outlets; (2) at the outlets of tideless rivers; (3) along tidal rivers; and (4) through tidal estuaries. Training-works in a non-tidal river serve to regulate the channel, in which the current, though varying in volume, always maintains a downward direction. The second case involves the more complicated problem of securing an adequate depth beyond the mouths of rivers flowing into tideless seas, where the enfeebled silt-bearing current, on emerging from the river channel into the open sea, tends to deposit its burden of alluvium. In tidal rivers, as the fresh-water discharge is supplemented by the tidal ebb and flow, the principles applicable to the training of non-tidal rivers require modification to suit the altered conditions. Lastly, the object in the fourth case is to form a stable navigable channel through the shifting sands of a wide estuary. The regulation of the Rhone between Lyons and the entrance to the St. Louis Canal, is a recent example of the training of a non-tidal river. The Rhone and the Volga furnish instances of attempts to train the outlets of tideless delta-forming rivers, which system was subsequently carried out with more successful results at the outlets of the Danube and the Mississippi. The Maas, the Adour, and the Nervion illustrate methods of training tidal rivers flowing directly into the sea; whilst the Weser, the Loire, and the Seine afford examples of tidal rivers opening into estuaries in which training-works have been carried out.

1. Training Non-Tidal Rivers.

Rivers exhibit in their natural condition frequent alterations in fall, and variations in width and depth, as well as a more or less tortuous course. The object of regulation works, in addition to straightening the channel by easing bends and substituting straight cuts for sharp turns, is to equalize the fall of the river by removing shoals and regulating the width of the channel, in order to obtain a more uniform depth for navigation. The worst passages and shallows are generally selected for improvement; but, unless the depth of the river above and below is ample, the works, by modifying the fall and the discharge in the trained portion, are liable to lead to the appearance or formation of fresh shoals beyond the limits of the training-works, by the lowering of the water-level above and the deposit of eroded material below. Theoretically, it would be possible, by means of continuous longitudinal training-walls, to secure the desired uniformity in depth for a definite discharge of a river; but, owing to the great variations in the discharge and in the quantity of detritus brought down by the current, and owing also to the differences in liability to erosion of the various strata constituting the bed of a river, and to the increased scour along the concave bank at curves, erosion in some places and deposit in others inevitably occur, so that the estimated available depth is never fully attained. Moreover, the depth obtainable during the low stage of a regulated river is dependent on the minimum discharge; and, therefore, the improvement of a river for continuous navigation by training-works alone has necessarily to be restricted to large rivers with an adequate low-water discharge, or to rivers in which, owing to special physical conditions, the low-water discharge rarely falls very low. Rivers, however, with a fair flow at their low stage, have been successfully improved by training-works, as for instance the Rhine, the Elbe, the Niemen, and other large rivers; whilst the Rhone furnishes one of the most recent examples of the improvement of a river for navigation by systematic training operations.

Rhone Navigation Improvement Works.

Physical Conditions of the River Rhone.—The drainage-area of the Rhone is 38,000 square miles, and is intermediate between the Seine basin which has an area of 30,370 square miles, and the Loire basin of 45,000 square miles. The mean fall of the Rhone between Lyons and the sea is about 1 in 2,000, or 2½ feet per mile, which

is seven times the mean fall of the Seine between Paris and the sea, and one-fourth greater than the mean fall of the torrential Loire between Roanne and the sea; and in some places the fall exceeds 1 in 250. Moreover, the Rhone carries down large quantities of shingle and gravel, which only finally disappear from its bed about 4 miles above Arles, where the great reduction in fall necessitates the trituration of the detritus into sand and silt before it can be carried to the sea by the enfeebled current. The flood discharge of the river is also considerable, attaining a maximum of 9,150 cubic yards per second just below the confluence of the Saône at Lyons, and 18,100 cubic yards per second at Beaucaire below the confluence of the Durance; whilst the current during great floods attains in some places a velocity of 20 feet per second, or over 13½ miles an hour.[1] The maximum observed discharge, indeed, of the Rhone just below Lyons, during a great flood in 1856, amounted to nearly four-and-a-half times the maximum discharge of the Seine at Paris during the great flood of March, 1876; and the maximum discharge at Beaucaire in the same flood was five-and-a-half times the maximum discharge of the Seine at Elbeuf, just above the tidal limit, during the great flood of December, 1882. The flow of the river being torrential, the floods subside rapidly; but the banks are low in many places, and the inundations are extensive.

Schemes for a Lateral Canal.—These unfavourable physical conditions have prevented the formation of any scheme for canalizing the river, a system which has been carried out with such excellent results for navigation on the Seine[2] and on the Main.[3] Schemes, however, have been brought forward for evading the obstacles to navigation presented by the river, by the construction of a lateral canal between Lyons and the sea—a solution of the problem adopted in the case of the Loire between Roanne and Briare. Thus in 1808, the construction of a canal was proposed along the right bank of the Rhone, starting from Lyons, and in 1822 along the left bank; whilst Mr. Krantz, in 1873, presented a Report to the Assembly,[4] advocating the formation of a canal along the right bank at an estimated cost of about £4,000,000.

Navigable Condition of the Upper Rhone and the River Saône.—The Upper Rhone is navigable from Le Parc down to Lyons, a dis-

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[1] "Travaux d'Amélioration de la Navigation du Rhône," H. Girardon.

[2] Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 224, and Plate 2.

[3] *Ibid*, vol. xcvi. p. 189, and Plate 6, Figs. 4 and 5.

[4] "Rapport à l'Assemblée nationale sur la situation des voies navigables dans le bassin du Rhône," 23 janvier, 1873.

tance of 95 miles, for vessels of 200 tons, which go down loaded and are drawn up empty; but the navigation is stopped when the river falls to its low-water stage, affording a minimum depth of only 2 feet. A side cut, rather over a mile long, with a lock in it, provides a passage for the navigation at Le Sault where the river is impeded by three falls.

The Saône being canalized right up to Corre, 233 miles from its confluence with the Rhone, places Lyons and the Rhone in communication with all the lines of inland navigation of central and northern France, by its junction with the Canal du Centre at Chalon, with the Bourgogne Canal at St. Jean-de-Losne, with the Rhone and Rhine Canal at St. Symphorien, and with the Canal de l'Est at Corre. The canalized Saône has an available depth of 6½ feet, the standard depth adopted for the main lines of inland water-ways in France, and accommodates vessels drawing 6 feet of water.

Flow of the Lower Rhone.—The length of the Lower Rhone, between Lyons and the sea, is 205 miles; and the flow of this portion of the river is rendered more regular by the different periods at which the greatest and least flow of the Upper Rhone and of the Saône occur. The floods of the Upper Rhone result from the melting of the snows and glaciers of the Alps, which form the sources of its tributaries the Arve and the Ain, and therefore occur in warm weather. The river is lowest in the winter, when frosts arrest all drainage from the mountains; and the flow of the Isère, which joins the Rhone below Lyons, is governed by the same causes. The Saône, on the contrary, rising in the Vosges, is swollen by winter rains, and falls to a minimum during the summer. A very low stage of the Lower Rhone is, accordingly, only reached when a prolonged winter follows a long period of drought; and, generally, the low-water flow of the Rhone immediately below the confluence of the Saône, is at least four times the low-water flow of the Seine at Paris, in spite of the torrential character of the Rhone, and the small difference between the drainage-areas of the two rivers. This moderate regulation of its flow, however, constitutes the only characteristic of the Lower Rhone favourable to its improvement for navigation by training-works.

Regulation of the Lower Rhone between 1860 and 1878.—In the earlier portion of this century the Lower Rhone, notwithstanding its serious impediments to navigation, attracted a good traffic. When, however, the railway was opened between Lyons and Marseilles, the trade naturally to a great extent left the river, on which

up-stream navigation was always difficult, and where the navigation was stopped nearly every year for about 100 days during the low stage, when the depth was occasionally reduced in places to $1\frac{1}{3}$ foot. Up to 1860, only works of protection against inundations had been carried out on the river; and nothing had been done for navigation beyond providing towing-paths. At that period, however, the demands of persons interested in the navigation resulted in works for the regulation of the river, in the worst places, between longitudinal training-walls, which were carried out from 1860 till 1870; and, after being stopped by the war, were resumed in 1876. The training-works, by confining the channel in the shallowest places between longitudinal stone embankments raised to the mean water-level, and shutting off secondary channels, concentrated the mean discharge of the river; so that it scoured away the shoals, and stopped the changes of the main channel at these places, which every flood had previously produced. These embankments, however, raised from $6\frac{1}{2}$ to 10 feet above the low-water level, had to be placed a sufficient distance apart to admit of the passage of the whole discharge of the river till the water rose above them; and they were consequently too far apart to confine and regulate the low-water flow, so that the low-water channel meandered between shoals, crossing over from one concave bank to that next below on the opposite side.[1] The current also, when completely filling the channel between these high embankments, scoured deep holes along the concave bends, so that the river, even in the trained portions, though considerably improved, was not uniform in depth. The removal, moreover, of the shoals, by facilitating the discharge, lowered the level of the river in the trained portions, which consequently increased the fall and reduced the depth above the ends of the training-works; so that the deepening of the channel in some places occasioned the appearance of fresh shoals in others. Accordingly, this method of training produced a shifting of the positions of the shoals and rapids, in place of the anticipated uniformity in depth and fall, and therefore did not adequately improve the navigable capabilities of the river at its low stage. It was consequently determined, in 1878, to modify materially the form of the training-works, and to train the Lower Rhone systematically, instead of merely improving the worst sections.

Systematic Training of the Lower Rhone.—The new training-works

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[1] "De l'Amélioration des Rivières navigables à fond mobile," M. Jacquet, Congrès international de l'Utilisation des Eaux fluviales, Paris, 1889, p. 164.

—which were commenced in 1878, were modified by the introduction of cross-dykes in 1882, and are now almost completed—have been designed with the view of altering the normal condition of the river as little as practicable, so as to avoid embarking upon a fruitless struggle with the natural forces at work in a river with a shifting bed.[1] Secondary channels have been shut off from the low-water channel of the river by low longitudinal training-walls, Fig. 3, Plate 1, or by a series of low cross-dykes arranged in steps, Fig. 5, so as to stop any scour in flood-time, when the course of the river is as free as formerly, and thereby prevent a subsidiary channel becoming the main channel. Sharp, irregular concave bends have been eased and regulated by forming low longitudinal training-walls of flatter curvature, projecting more or less into the channel along the concave river-banks and connected with the land by cross-dykes dipping towards the channel and inclined slightly up-stream, so as to prevent erosion at the back of the training-walls, and to direct the current behind these walls into the main channel, Figs. 1 to 5, Plate 1. These longitudinal training-walls are intended merely to regulate the low-water channel of the river; and their height is, therefore, restricted to 3 or 4 feet above the low-water level. The low-water channel, moreover, is further regulated along these bends, and an undue deepening along the toe of the longitudinal walls obviated, by placing dipping submerged cross-dykes or spurs in the channel in front of the longitudinal walls and pointing slightly up-stream, Figs. 1, 2, and 5. These cross-dykes also protect the toe of the longitudinal walls from scour; and by directing the main current into a more central channel away from the banks, facilitate the passage of vessels at these bends; further, by arresting erosion of the bed, they prevent the loss of fall, and consequent lowering of the water-level which generally occurs at sharp bends, producing a diminution in depth over the shoals above. Longitudinal and transverse dykes have also been used to direct the main channel in its passage over the shoal at the change of curvature between the successive bends; so that it may pass gradually, with only a slight reduction in depth, from one concave bank to the next, instead of with the abrupt transition, almost at right angles to the general course of the river, which is sometimes found at irregular parts of the river—offering a very serious impediment to navigation, both on account of the tortuous line of the channel, and the shoal which invariably exists at these

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[1] "Travaux d'Amélioration de la Navigation du Rhône," H. Girardon.

points, Figs. 1 and 5, Plate 1. In some places, dipping cross-dykes alone have sufficed to regulate the low-water channel, Figs. 4 and 5; and longitudinal training-walls have not been placed along the gently-sloping foreshore on the convex side of a bend; but occasionally this foreshore has been protected from scour by low cross-dykes, Fig. 3, to prevent a diversion of the channel during floods. Where deep places existed in the centre of the channel, occasioning a reduction of the fall of the water-line and a consequent increase in the fall above, submerged dykes have been placed in mid-channel, inclined slightly up-stream in the centre, Figs. 2 and 4, which, by raising the fall of the water-line in these places, diminish the fall and increase the depth above. These submerged dykes are kept below the limit of the navigable depth; and they serve, like the submerged spurs projecting in front of the concave longitudinal training-walls, to regulate the depth of the channel, just as the other training-works regulate its width. Their form, moreover, directs the main current into a central course. By the judicious and gradual adaptation of these different forms of training-works to the various requirements of the channel, the fall, depth, width, and course of the low-water channel have been regulated between Lyons and the St. Louis Canal, without unduly interfering with the natural condition of the river. All the training-works consist of rubble stone mounds, deposited at random under water. The cross-dykes are raised in stages, accretion meantime taking place. After the mounds have become consolidated, the portions above low water are filled up solid with concrete; and the surfaces of the portions under water are arranged by the aid of a diving-bell.

Results of the Lower Rhone Training-Works.—The low-water line adopted as the standard on the Lower Rhone was the lowest water-level that had been recorded at the commencement of the works; and though the river fell below this line in 1884, under very exceptional conditions, the water very rarely falls as low as this line. In 1878, there were 5 places where the depth was less than $1\frac{2}{3}$ foot below the low-water line, 81 less than 4 feet, 91 less than $4\frac{1}{4}$ feet, and 111 less than 5 feet; whereas in 1892, no part of the river had a less depth than 4 feet below the low-water line, only 2 places less than $4\frac{1}{4}$ feet, and 12 places less than 5 feet. The minimum available depth has, in fact, been increased by the new training-works from under $1\frac{1}{3}$ foot to over 4 feet; and since 1885, the traffic has never been stopped for want of depth. As, however, the low-water standard represents an exceptional condition of the river, the practical improvement realised, and the actual value of the river

for navigation are better indicated by the periods during which certain depths of water are maintained. Thus, whereas an available depth of over 4½ feet was maintained during 227 days in 1878, this period has been increased by the training-works to 357 days; the period of a depth exceeding 5¼ feet has been increased from 182 to 341 days; exceeding 6 feet, from 139 to 317 days; and exceeding 6½ feet, from 101 to 282 days. These figures show clearly how much the prolongation of the period corresponding with a given depth, effected by the training-works, increases for greater depths. The navigable capabilities of the Lower Rhone have, accordingly, been considerably increased by affording a depth of 6½ feet for more than nine months in the year, which may be eventually extended to ten months, in place of little over three months, and also by securing a minimum depth of slightly over 4 feet, only 10 inches less than the minimum depth of the Rhine between Bingen and St. Goar, which, on the completion of the works will probably slightly exceed 4½ feet, in place of the minimum depth of 1⅓ foot previous to 1878.

The above figures, however, do not represent all the advantages derived from the works by the navigation; for the training-works, by rectifying the channel between the bends, by easing the curvature at the bends, and keeping the channel away from the concave banks, and by reducing the current at the rapids, have enabled vessels to follow the deepest channel, and have greatly facilitated their manœuvres. Moreover, the raising of low bridges has materially reduced the period during which the navigation is interrupted by floods; which interruption now only occurs when the height of the river exceeds 14¾ feet above the low-water line, lasting on the average only four days in the year. The average period, indeed, of the stoppage of navigation on the Lower Rhone by ice, wind, fogs, inadequate depth, and floods, has been reduced by the works from 91 days to 14 days in the year, making an annual gain of 77 days. The period during which the navigation is difficult, when vessels have to be lightened or are handled with difficulty, has, moreover, been reduced from 129 days to 14 days in the year, making a further gain of 115 days annually. Consequently, the period during which navigation on the river is easy has been prolonged from 145 days to 337 days—a total increase of 192 days in the year; and the navigation is subject to delays or suspension for barely a month in the year, instead of over seven months.

The navigation works have also benefited the riparian landowners by fixing the channel of the river, and thus securing the

adjacent lands from erosion by the shifting of the channel. Moreover, accretion is taking place behind the training-works, creating new land suitable for cultivation in the spaces between the cross-dykes. These areas must, however, be kept low, and reclamation forbidden, so that they may remain available for discharging the flood waters of the river. Nevertheless, as the current will follow the dip of the cross-dykes towards the main channel, the water will flow off on the lowering of the river, and these lands will be valuable for growing some kinds of crops.

Cost of the Lower Rhone Training-Works.—The expenditure on the training-works since 1878 up to the end of 1892, amounted to £1,568,000, of which £100,000 were spent in maintenance. A balance of £220,000 still remains to be expended before the original estimate is reached; and it is stated that the cost of the works remaining to be done will not exceed this sum. As, however, the scheme of 1878 was materially modified during the course of the works—necessitating the removal of portions of the earlier works—the existing training-works could undoubtedly have been constructed at a smaller cost.

Navigation of the Lower Rhone.—As the portion of the Rhone between Lyons and Arles does not always afford a depth of 6½ feet of water, it is placed in the second class of French inland waterways; whereas the 29 miles of river beween Arles and the St. Louis Canal belong to the first class, as the depth never falls below 6½ feet in this portion. Nevertheless, owing to local conditions, and the branching off of the Rhone and Cette Canal at Beaucaire above Arles, the traffic between Arles and St. Louis is considerably less than in the shallower and rapid river above. After the introduction of railway competition, the traffic on the river fell at one time to about 200,000 tons in the year; but it gradually revived with the aid of the earlier training-works, reaching about 400,000 tons annually previously to the improvements effected by the new training-works. Since 1881, when the influence of the new works began to operate, the traffic between Lyons and Arles has increased fairly steadily; and the total tonnage reached a maximum of 707,500 tons in 1890. This tonnage, however, fluctuates considerably, being greatly affected by the supplies of building materials carried short distances to various parts of the river; and the actual traffic on the river is far more correctly indicated by the mean tonnage over the whole length of this section of the river, which is obtained by dividing the total number of tons carried one mile by the length of the section in miles. Now the mean tonnage of the river traffic, spread over the whole 176 miles between Lyons and

Arles amounted to 183,500 tons in 1881, 193,000 tons in 18
tons in 1889, and 254,000 tons in 1892, exhibiting a gen
increase, in spite of slight occasional declines for a year

Notwithstanding the impediment offered to up-stream by the rapid current, the mean tonnage of the go up-stream has become nearly equal to the mean down-st namely 125,200 tons up-stream, as compared with 1 down-stream in 1892, owing to the very large amo cultural products and articles of food conveyed lo up-stream, amounting to two-fifths of the total mean

The traffic between Lyons and Arles is carried on and by barges descending with the current, and draw empty or half-loaded by grappling tugs. The ca paddle-steamers of 300 to 400 tons, drawing 5 t water, descend the river at an average speed of hour, and go up-stream at about 3¾ miles an hour. T steamers of 60 to 120 tons have a draught of 3¼ to barges of between 30 and 300 tons float down-strea to 4⅓ miles an hour, and are towed up by tugs grappl by the aid of a large wheel, at the rate of about 3 The traffic has nearly reached its limit with the but tugs are in course of construction for hauling on which it is hoped will raise the annual traffic to a

Remarks.—Dipping and submerged dykes, which most interesting feature of the Rhone training-w previously adopted for training some of the Germany; but the Rhone furnishes a somewhat n a long length of river being systematically trained in conjunction with longitudinal walls. The Rh river of France suitable for this method of improv owes to the difference in the period of the low-w affluents. Though the increase of nearly three fe depth at the low-water stage is small in comparis ening that can be effected by canalization, it com with the improvements attained in larger rivers b Moreover, the training-works do not practically in flood-discharge and the descent of detritus; as they the low-water discharge, and prevent the undue detritus at the passages between the bends, withou ating the succession of pools and shallows which

[1] "Statistique de la Navigation Intérieure," Ministère d
Paris.

natural condition of the river channel. Provided a depth suitable for inland navigation can be maintained throughout the year, local conditions exercise a greater influence on the traffic than a large increase in depth. Thus the traffic on the most frequented portion of the Upper Seine just above Paris, with a minimum depth of 6½ feet, greatly exceeds the traffic on the lower portion of the Lower Seine, with a minimum depth of 10½ feet, on account of the trade converging to Paris. The traffic already developed on the Lower Rhone since its regulation, indicates that the depth achieved is adequate for inland navigation; and, though the Rhone is not likely to be improved sufficiently to be raised to the first class of inland waterways in France, with a minimum depth of 6½ feet, improved means of towage and competition in the river traffic may materially increase its trade. The Rhone, however, is prejudiced by the absence of inland water-communication with Marseilles, necessitating the transhipment of goods at St. Louis; and a canal for river craft between the Rhone and the port of Marseilles would greatly promote traffic on the river.

2. Training the Outlets of Tideless Rivers.

Contrast between the Outlets of Tideless and Tidal Rivers.—Sediment-bearing rivers flowing into a tideless sea, are obstructed at their outlet by the deposit of the alluvium they discharge into the sea, which gradually accumulates, reducing the fall of the river near its mouth and forming a delta. The bars, accordingly, at the mouths of these rivers are wholly of fluvial origin, differing in this respect from the bars of tidal rivers, which result from the drift of sand and shingle along the coast tending to form a continuous strand across the river mouths, an action that is only partially prevented by the ebb and flow of the tide, aided by the fresh-water discharge. The bars also of delta-forming rivers project considerably in advance of the general coast-line, together with the mound of deposit composing the delta; so that waves sweeping across the outlet, and littoral currents arrest more or less the advance of the delta, and the formation and seaward progression of the bar. The bars of tidal rivers, on the contrary, being formed by detritus from the coast and cliffs, are only slightly pushed out in advance of the general line of the foreshore by the current of the river, and are raised by storms driving a large quantity of detritus along the shore.

Physical Conditions affecting the Outlets of Tideless Rivers.—When the direction of the prevalent winds directly faces the outlet of a tideless river, the turbid current is more rapidly arrested and

deposit promoted thereby. The condition also of the outlet of a tideless river is affected by the proportion of solid matter brought down by the current, and by its density. The larger the volume of sediment in a given discharge, the more rapid will be the advance of the delta, and the shorter will be the duration of beneficial effects from training-works. Moreover, if the material is light, it may be carried some distance out in suspension, and brought under the influence of littoral currents or wave-action, and dispersed; whereas dense matter, rolled along the bottom, soon comes to rest when the current is checked on emerging into the sea, and mainly forms the bar which is invariably found in front of delta outlets. As the mound of deposit is constantly advancing seawards like a submarine embankment, emerging by degrees out of water at the sides of the land end of the outlet channel, the depth of the sea in front of the delta forms an important element in its rate of progression and in the advantage of training the outlet. Accordingly, the direction of the prevalent winds, the existence of littoral currents, the volume and density of the alluvium, and the depth of the sea, are considerations on which the practicability and value of improvement works at the outlet of a tideless river depend.

Principles of Training-Works at a Delta Outlet.—Only two methods are available for deepening the navigable channel across the bar in front of the outlets of delta channels; namely, dredging on the bar, and making the river current scour the bar by confining it between parallel jetties, in prolongation of the natural banks, out towards the bar. Harrowing on the bar, so as to stir up the sediment for the current to carry it out to sea, which was tried on the Danube and the Mississippi, naturally failed; for the enfeebled current crossing the bar could not bear away an additional burden when dropping the matter with which it was already charged. The great volume of sediment generally brought down by large rivers flowing into a tideless sea, restricts the economical application of dredging to a small increase in depth, and necessitates continuous dredging operations. The depth of one of the outlet channels of the Volga has, indeed, been increased from 4 to 8 feet by dredging; and it is hoped that a depth of 14 feet may be obtained by powerful dredgers at the mouth of another channel. As, however, every additional foot of depth involves a very large increase in the volume of material to be dredged, and in the cost of maintenance, recourse has been had to the scour of the trained current for the considerable improvement in depth required at the outlets of the Danube and the Mississippi.

In order that the training-banks, in prolongation of the natural banks of the outlet-channel, may make the river current scour the bar and also convey its burden of sediment into deep water, the training-works require to be carried out to the bar. As the bar is nearer to the outlets of the delta channels which have a proportionately small discharge, shorter training-works suffice for a minor channel than for a large one; and as the advance of the delta in front of the various outlets is proportionate to the discharge, other conditions being similar, the efficiency of the training-works continues for a longer period in front of a minor outlet—deferring the necessity for prolonging the training-banks, which the gradual accumulation of deposit eventually occasions. The selection of the outlet to be trained is the only condition which is under the control of the engineer; and the above considerations show that a minor outlet should be selected, if the delta channel leading to it is adequate for the requirements of navigation. The choice also must be guided by any advantages in strength of littoral current and depth, which may exist in front of some outlets over the long stretch of coast-line occupied by a delta. In the absence of any littoral current or other disturbing cause, and where the sea is shoal for a long distance in front of a delta, it would be inexpedient to attempt to improve the outlet-channel of a silt-bearing river across its bar by training-works, owing to the rapid accumulation of deposit that would inevitably take place in front of the training-banks.

Training the Kamysiak Outlet of the Volga.

The Volga has a total length of 1,980 miles, and a basin of 563,000 square miles. It becomes to some extent navigable about 60 miles from its source, and it is fully navigable from Tver, 220 miles further down, to its mouth.

Delta of the Volga.—The delta of the Volga commences about 31 miles above Astrakhan, where the Buzan branch diverges from the main channel; and its area is about 5,300 square miles. Near Astrakhan and below, other channels branch off, and subdivide lower down, so that eventually the Volga flows into the Caspian Sea through at least two hundred mouths.[1] The Volga has an unusually small fall, even in the earlier portion of its course; and the large quantity of alluvium brought down, comes mainly from

[1] "Les Embouchures du Volga," V. E. de Timonoff. V^me Congrès International de Navigation intérieure, Paris, 1892.

the erosion of high cliffs which border its channel in places. Observations indicate that 26,000 cubic yards of solid matter have been carried down by the river per day during a flood, which, however, bears a small ratio to the maximum discharge of the river in flood-time, averaging about 27,000 cubic yards per second. The rapid progression of the Volga delta, if correctly estimated at 1,270 feet per annum, can only be accounted for by the shallowness of the northern part of the Caspian Sea, which appears to have decreased between 2 feet and 7 feet in depth in the last fifty years, owing to the quantity of alluvium brought into it by the Volga and other rivers.

Out of the numerous, changeable channels of the Volga delta, two only are used at the present time for navigation between Astrakhan and the sea, namely, the Bakhtemir and the Kamysiak branches. The former channel is the most frequented, as the normal depth over its bar has been increased from 4 feet to 8 feet by dredging; whereas the depth over the Kamysiak bar is only 4½ feet. In other respects, however, the Kamysiak channel is the best, as it is much straighter, shorter, and generally deeper than the other; and the 3-fathom line of soundings in the Caspian Sea approaches much nearer the Kamysiak mouth than to the other outlets. The advance also of the delta must be much more rapid in front of the Bakhtemir outlet, since one-third of the whole flow of the Volga is discharged by this channel.

Training the Volga Outlet.—Works for deepening the outlet of the Kamysiak branch of the Volga to 8 feet were commenced in 1859, and comprised closing secondary branches, confining and concentrating the current in the main channel by training-banks of fascine mattresses, and dredging on the bar. These works were carried out up to 1869, at a cost of £160,000, the training-works being extended seawards about 4⅔ miles. These mattress banks, however, were discontinuous and fragile in construction, being merely intended as a nucleus for the accumulation of silt, so they were frequently injured by waves and ice; and the banks did not become sufficiently filled with deposit to guide the current properly. The works, moreover, only extended into a depth of 8 feet, with a gently sloping sea-bottom in front. Thus with imperfect training-banks, and under unfavourable physical conditions, it was natural that no material improvement in depth was obtained. The conditions, indeed, of the Volga delta seem to preclude the adoption of training-works for the improvement of the outlet, even if rapidly and efficiently carried out; for besides the absence of adequate depth to provide a reservoir for the

deposit of the alluvium brought down by the current, there is no sea-current along the northern shore of the Caspian, and the prevalent winds of north-west and south-east cannot create a littoral current, and thus disperse the suspended matter. If a depth of 14 feet could be obtained and preserved by dredging over the Kamysiak bar, this would provide the maximum increase in depth obtainable at a reasonable cost for the Volga outlet, for the available depth in the Kamysiak branch up to Astrakhan is only 14 feet; whereas the available depth in the Bakhtemir branch is limited to 8 feet; and the lowering of the crest of the Bakhtemir bar to 14 feet, would, owing to its great width, necessitate dredging several miles of channel.

Training-Works at the Mouth of the Rhone.

Delta of the Rhone.—The large quantity of detritus brought down by the Rhone, being gradually triturated so as to be wholly converted into sand and mud below Soujean, has by degrees formed the delta of the Rhone, which is considered to commence about 5 furlongs above Arles, where the Little Rhone branches off from the main river. In Roman times Arles was an important town, owing to its maritime position;[1] but now it is 32 miles inland from the mouth of the Great Rhone, through the advance of the delta. The Great Rhone, carrying 84 per cent. of the discharge of the river, is the navigable channel, and formerly entered the Mediterranean sea through six mouths; and the advance of its delta has been estimated at 140 feet annually. Mr. Guérard calculates that the Great Rhone carries 23,500,000 cubic yards of solid matter annually into the sea, which is rather less than one two-thousandth of the volume of water discharged;[2] and this material consists mainly of fine sand rolled along the bed of the river, less than a fourth of the alluvium being found in suspension in the current. The heaviness of this detritus is doubtless due to its being derived from the primitive rocks of the Alps.

The Mediterranean Sea attains a fair depth at a moderate distance from the shore in front of the Rhone delta; but the inner bay of Foz, to the east of the delta, is comparatively shallow. The strongest and most prevalent winds blow from the north-west and south-east; and the latter wind, blowing from the sea, brings the

[1] "Le Rhône, Histoire d'un Fleuve," Charles Lenthéric, vol. ii. p. 371.
[2] Minutes of Proceedings Inst. C.E., vol. lxxxii. p. 309.

greatest waves on to the coast. A permanent littoral current also travels slowly along the Mediterranean coast from east to west, extending to considerable depths; whereas the surface-currents occasionally observed in the bay of Foz are very slight.

In 1841, the deepest outlet was through the southern Eugène Channel, between the alluvial islands of Roustan and Eugène,[1] with a depth of 6½ feet over the bar, Fig. 11, Plate 1. In 1852, there was an average depth of 5 feet over the bars in front of the Piémanson and Roustan channels; whilst the depth over the Eugène bar had fallen to nearly 4 feet, and the depth over the bar of the direct eastern channel was only 3½ feet. Accordingly, all the physical conditions at the Rhone delta were favourable to the selection of one of the southern outlets for improvement, preferably the central Roustan channel, as being wider and in a better direction than the westerly Piémanson channel; also as opening more directly into the Mediterranean, and having a better depth over the bar than the Eugène channel. The eastern and northern mouths, discharging their sediment into the shallow bay of Foz, and beyond the influence of the littoral current, were unfavourably situated.

Training the Rhone Outlet.—The east channel was chosen for training, as its direction was considered the most favourable for the entrance and exit of vessels; embankments on each side were commenced in 1852, about 4 miles in length, and were completed in 1857, terminating rather more than ½ mile short of the crest of the bar. These embankments closed the southern and northern channels, and concentrated all the discharge of the river, and, consequently, all the alluvium, in the eastern outlet. The training-works produced a temporary deepening of the eastern bar, reaching a maximum of 9¾ feet average depth in 1856, which has never since been attained, even in the exceptionally good year 1873; whilst the average depth in the last thirty years has amounted to only 6¼ feet,[2] less than the recorded depth over the Eugène bar in 1841. The bar, moreover, has been gradually advancing across the entrance of the bay of Foz; its rate of advance between 1863 and 1873 having reached 360 feet a year, two and a half times the estimated progression of the delta before the commencement of the works. The advance, however, appears to have become much less rapid in the last eighteen years, Fig. 11, Plate 1, owing doubtless

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxii. Plate 6, Figs. 3 and 5.

[2] "Amélioration de l'Embouchure du Rhône," A. Guérard, p. 30, V^{me} Congrès International de Navigation intérieure, Paris, 1892.

the extended zone for deposit which the current has acquired ther out; and the eastern outlet will probably eventually split into two or three mouths. The bar in travelling out becomes re exposed, but this is immaterial for navigation, as vessels ve deserted this route for the St. Louis Canal (opened in 1873), ich affords a navigable depth of 20 feet for sea-going vessels come up to St. Louis, where the transhipment of cargoes takes ce. The advance of the delta eastwards across the bay is ren- ing the approach to the St. Louis Canal, and to the port of uc, from the west, more circuitous: whilst since the closing of southern outlets, the sea has eroded the southern shore of the ta. Accordingly, the re-opening of one of the southern channels been proposed.

The failure of the training-works at the outlet of the Rhone ist be attributed to the selection of an unfavourably situated let, to the closing of the other outlets concentrating all the sedi- nt of the Rhone into a single channel, and to some extent to the rks not being carried out rapidly and extended to the bar, which uld have increased and prolonged the temporary improvement depth. The training of the Roustan Channel right out to its r, whilst leaving all the other channels open, would have offered r better prospects of success, and would probably have secured a ir increase in depth, in spite of the density of the alluvium and e feeble scouring power of the littoral current except during orms.

Training-Works at the Sulina Mouth of the Danube.

Delta of the Danube.—The delta of the Danube has been fully scribed in a Paper[1] by Sir Charles Hartley, M. Inst. C.E. The anube drains an area of about 312,000 square miles, and brings wn in flood-time large quantities of comparatively light alluvium, ostly in suspension in the current, and has gradually formed a lta which is 1,000 square miles in extent. The average flow of e Danube varies between 4,600 cubic yards per second at a low age and 12,000 cubic yards at a high stage; but at extreme low- ater its discharge falls to nearly half the first volume, and in traordinary floods it exceeds three times the latter discharge. he proportion of alluvium brought down in suspension to the scharge is much greater in flood-time than at a low stage, nounting on the average to 1 in 6,700; but some denser materials

[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 277.

must be rolled along the bed during floods, of which no measurement has been made.

The Sulina mouth, selected for improvement, was the most suitable in most respects, for it discharges barely one-thirteenth part of the whole flow of the river, and consequently, the advance of the delta in the neighbourhood of this mouth was comparatively slow, averaging about 94 feet a year; its bar also was much nearer the shore than the bars at the outlets of the other two branches, and the channel over it was deeper. The northern Kilia branch, which is the main channel through the delta, was, indeed, quite unsuited for improvement at its outlet, with its numerous shallow mouths and its rapidly advancing delta. The southern St. George's branch possessed a better navigable channel through the delta than the central Sulina branch, and the sea sloped more rapidly down in front of its outlet; but these advantages were outweighed by the greater actual depth across the Sulina bar, and by this bar being only half the distance from the shore of the St. George's bar, so that training-works of half the length required for the St. George's mouths sufficed at the Sulina mouth.

A large portion of the alluvium brought down by the Danube is carried out to sea;[1] and the lightness of this matter is further indicated by the form of the Sulina bar as compared with the Rhone bar, Figs. 7 and 11, Plate 1. The sea-slope of the Rhone bar is comparatively steep, as most of the dense sediment rolled along the bottom comes to rest before passing the crest of the bar, and is only gradually pushed over on to the outer slope; whereas the sea-slope of the Sulina bar is flat, as a good deal of the relatively light sediment of the Danube is carried beyond the crest of the bar, and is deposited along the outer slope by a sort of sifting process, according to its density, the heavier portions being deposited first. A littoral current flowing towards the south in front of the delta, gives a southerly drift to the alluvium; and the prevalent northerly winds make the waves exert a similar influence on the deposit near the shore.

Training the Sulina Outlet.—The jetties constructed provisionally at Sulina in 1858-61, and consolidated in 1866-71 have been described in detail by Sir Charles Hartley.[2] These training-works, extending nearly a mile in advance of the former shore-line, were carried out beyond the site occupied by the crest of the bar in 1857, and thus concentrated the scour of the issuing current right across

[1] Minutes of Proceedings Inst. C.E., vol. xci. p. 335.
[2] *Ibid*, vol. xxxvi. p. 201.

the bar, Fig. 6, Plate 1. The bar was thereby pushed seawards; and the depth over it increased from about 10 feet in 1857 up to 20 feet in 1872, which depth has since been maintained, Fig. 7. Owing to the jetties projecting from the coast like a groyne, the waves and littoral current have eroded the shore to the north, and have produced a retrogression of the lines of soundings towards the land down to a depth of four fathoms. On the southern side of the Sulina mouth, on the contrary, the shelter of the jetties has occasioned an advance of the shore-line, and promoted deposit. The lightness of the alluvium, and the influence of waves and the littoral current have hitherto prevented the raising of the bar; but the deposit to the south has deflected the channel beyond the jetties towards the north, and has sometimes reduced the depth in the direct line of the jetty channel below 18 feet. Moreover, the gradual flattening of the sea-slope of the bar, and the receding of the four and five fathom lines seawards in front of the jetties, as much as a quarter of a mile between 1871 and 1891, show that, in spite of over 85 per cent. of the alluvium in suspension being carried more than $1\frac{1}{3}$ mile beyond the pier-heads, and the very small proportion of heavy detritus brought down, the bed of the sea in front of the jetty channel is gradually shoaling, which must in time produce a raising of the bar, and eventually necessitate a prolongation of the jetties.

The tonnage of laden vessels leaving the Sulina mouth, which was about 300,000 tons in 1857, rose to over 400,000 tons in 1860, and with occasional fluctuations, had increased to nearly $1\frac{1}{2}$ million tons in 1889. The navigation along the Sulina branch through the delta was formerly considerably impeded by shoals at the low stage and a tortuous channel, which led to an expression of preference at the outset for the St. George's branch. Training-works, however, aided by straight cuts and dredging, have gradually increased the minimum depth at the lowest stage of the river from 7 feet up to about 17 feet.[1]

Training-Works at the South Pass of the Mississippi.

Delta of the Mississippi.—The delta of the Mississippi is considered to commence just below the confluence of the Red river, 316 miles from the outlet of the river; and it extends over an area of 12,300 square miles.[2] It projects about 200 miles into the Gulf of

[1] Minutes of Proceedings Inst. C.E., vol. cvi. p. 239.

[2] "Report on the Physics and Hydraulics of the Mississippi River," Humphreys and Abbot, p. 452.

Mexico, and its formation has been estimated to have occupied at least 4,400 years. Within 35 miles of the gulf, the main channel passes Fort St. Philip with a width of 2,470 feet, and a depth of 120 feet; but 20 miles lower down, the river, having widened out to $1\frac{3}{4}$ mile with a reduction in depth to 30 feet, divides into three very divergent branches, two of which finally split up again, so that the discharge into the gulf takes place through seven mouths. The Mississippi has a basin of 1,244,000 square miles; the discharge of its main channel amounts, on the average, to 23,000 cubic yards per second; and the average yearly amount of alluvium carried into the Gulf of Mexico is nearly 300 million cubic yards, equivalent to $\frac{1}{2,420}$ of the total discharge. The alluvium brought down consists of silt, sand, and clay, a considerable portion of which is rolled along the bed of the river, estimated at one-tenth of the whole; and the presence of this dense sediment is manifested by the steep sea-slope of the bar, Fig. 9, Plate 1. The yearly advance of the delta is 300 feet at the mouth of the South-west Pass which conveys one-third of the total discharge, 260 feet at the mouth of the Pass à l'Outre which carries one-fourth of the discharge, and it was formerly 100 feet at the mouth of the South Pass, discharging only one-tenth of the flow. The normal depth over the bar of the South-west Pass is 13 feet, which was increased for a time by dredging to 18 feet; and this formed the only navigable outlet of the Mississippi for some years previously to 1876. The bar, however, of this pass is 5 miles beyond its outlet; whereas the bar of the South Pass was only $2\frac{1}{4}$ miles from the end of the pass, though the depth over it was only 8 feet. A littoral current flows from east to west in front of the delta, mainly due to the prevalent easterly winds.

The slope of the sea-bottom in front of the Mississippi delta approximates to that of the Mediterranean Sea to the south of the Rhone delta, but has about four times the inclination of the bed of the Black Sea in front of the Danube delta.

South Pass Jetties.—The South-west Pass outlet would have been preferred for improvement by training-works, as besides the greater depth over its bar, this pass possessed a better navigable channel through the delta; but the distance of the bar from the shore, as compared with the South Pass bar, led to the selection of the South Pass outlet from motives of economy as in the case of the Sulina mouth.[1] Two parallel jetties, formed of fascine mattresses,

[1] "A History of the Jetties at the Mouth of the Mississippi River," E. L. Corthell.

weighted with concrete blocks at their outer ends, and placed 1,000 feet apart, were carried out $2\frac{1}{4}$ and $1\frac{1}{2}$ miles, in 1876–79, in prolongation of the South Pass as far as the bar, Fig. 8, Plate 1, and *Fig. 10.* They terminate together in 30 feet of water, having been curved slightly towards the south at their extremities, so as to bring the discharge more directly under the influence of the littoral current flowing from east to west across the ends of the jetties. The low-water stage of the jetty channel has been further regulated, and the scour in the centre increased, by an inner line of mattresses on each side. These training-works soon removed the bar, and increased the depth in the outlet channel to 31 feet; and the required depth of 30 feet was continuously maintained from July 1879 up to April 1891, Fig. 9. The concentrated current has in fact brought the lighter alluvium under the influence of the littoral current, and has rolled the heavier sediment into deep water beyond the outlet. This sediment, however, is gradually accumulating seawards of the jetty channel; and within a fan-shaped area of $1\frac{1}{4}$ square mile in front of the outlet, the decrease in depth between 1876 and 1892 reached over 13 feet on the average over the whole area, equivalent to an annual shoaling of rather more than 9 inches.[1] The shoaling, moreover, is becoming more rapid, for in the first four years it was only 1 foot, whereas in the last four years it amounted to 4 feet. The accumulation is greatest in the outer zone of the area, between 4,000 and 6,000 feet beyond the jetties, and also on the western side, to which the sediment is deflected by the littoral current. The advance of the lines of soundings also indicates the progress of deposit in front of the jetties, which extends considerably beyond the limits of the area surveyed annually. The maximum advance has taken place in the 70-foot line since 1877, amounting to an average annual progression of 104 feet; but the 100-foot line, the limit of the yearly observations, is advancing at the average rate of 81 feet a year, and extends now 7,700 feet beyond the ends of the jetties, indicating how far out the shoaling must prevail. This deposit is gradually raising the sea-slope in front of the jetties; and there are already indications of the commencement of the growth of a bar near the outlet,

Fig. 10.

Scale $\frac{1}{800}$.

MISSISSIPPI, SECTION OF SOUTH PASS JETTY.

[1] "Annual Report of the Chief of Engineers, United States Army, for the year 1892," Part 2, p. 1478.

Fig. 9. The depth of the jetty channel has, indeed, on two occasions during the last two years, fallen below the standard depth of 30 feet, namely for eleven days in 1891, and for a month in 1892; and though the deepest, circuitous easterly channel beyond the ends of the jetties has just maintained a depth of 30 feet, the depth in the direct prolongation of the jetty channel was only 26·4 feet during July 1891, and had to be deepened by dredging. Accordingly, to maintain the 30-foot depth in a navigable channel in front of the jetties, it will become increasingly necessary to resort to dredging; and before long a prolongation of the jetties will be required.

Conclusions from Results of Works at Tideless Outlets.

The results of the training-works at the outlets of tideless rivers, just described, prove the influence exercised by the dip of the sea-slope in front of a delta, by the action of any littoral current, and by the volume and density of the alluvium brought down, on the extent and permanence of the improvement in depth effected by the training-works. If the sea-slope is very flat, so that the depth is shallow for a long distance out, as in the Caspian Sea in front of the Volga delta, and no littoral current exists, it is impossible by training-works of reasonable length to convey the deposit into deep water, so that any improvement effected under such conditions is very transitory, even when the proportion of alluvium is moderate, as in the case of the Volga. Such an outlet is only capable of very limited improvement of depth by dredging, depending on the width of the crest of the bar, and the expenditure on dredging which the prospects of an improved navigation may justify.

The relative permanence of the depth obtained at the Sulina mouth, compared with the South Pass outlet of the Mississippi, shows that a littoral current exerting a powerful erosive action, combined with an alluvium comparatively moderate in volume and of low specific gravity, as in the case of the Danube, though with only a moderate dip of the sea-bottom in front, may prove more favourable to the maintenance of an improved depth than a considerably steeper sea-slope accompanied by a feebler littoral current, and a larger volume of alluvium in proportion to the discharge of notably greater density, such as exist at the Mississippi outlet.

The success achieved in deepening the channel over the bar, both at Sulina and the South Pass, manifests the advantage, as

well as economy, of improving one of the minor outlets, provided its delta channel can be made to satisfy the requirements of navigation.

The alluvium of the Rhone appears to be heavier than that of the Mississippi, as might have been anticipated from its origin, and is, indeed, indicated by the steeper sea-slope of its bar, Figs. 9 and 11, Plate 1; but in other respects the physical conditions at the Rhone delta approximate to those of the South Pass, for the slopes of the sea-bottom in front are similar; and whereas the proportion of alluvium to the discharge is slightly the largest in the Rhone, it is probable that the littoral current along the Mediterranean coast is stronger and extends deeper than in the Gulf of Mexico. Accordingly, though the density of the Rhone alluvium would have prevented training-works producing equally successful results at the outlet of the Rhone as at the South Pass, the training of one of the southern outlets of the Rhone, without obstructing the flow through the other mouths, would doubtless have notably improved the depth over the bar of the trained channel. The Rhone training-works, however, as carried out, demonstrate the fatal consequences of selecting an unfavourably-situated outlet for improvement, and of concentrating the whole volume of heavy alluvium into the channel intended for navigation. Probably, the foresight and perseverance of Sir Charles Hartley, in urging the construction of training-works for the improvement of the navigable outlet of the Danube, in preference to dredging or a ship-canal, alone prevented the failure of the training-works at the mouth of the Rhone from postponing for a long period the adoption of the only system by which the outlets of silt-bearing rivers flowing into tideless seas can be very effectually improved.

3. Training of Tidal Rivers.

The tide flowing into a river, by largely increasing the volume of water in the river, and by reversing the current twice a day, introduces modifications into the problem of river-training. Admitting that the great value of the tidal ebb and flow in maintaining the outlet of a river, and increasing its navigable capabilities, has been fully established,[1] it follows that no impediment

[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 18; "Rivers and Canals," L. F. Vernon-Harcourt, pp. 229-236; "The Physical Conditions affecting Tidal Rivers, and the Principles applicable to their Improvement," L. F. Vernon-Harcourt, Manchester Congress on Inland Navigation, 1890.

should be offered to the influx of the tide to its fullest extent. Accordingly, the width between the training-walls regulating the channel should be gradually enlarged in descending towards the sea, so that the volume of tidal water flowing up past any point may be sufficient to fill completely the whole of the tidal channel above it. The width, moreover, should not be reduced across shoals in order to increase the depth by scour, for any narrowing of the trained channel checks the influx of the tide, and reduces the volume of the ebb; whilst the material scoured from the shoal would be liable to be deposited at the mouth; and dredging must be resorted to in such cases for regulating the depth. Indents, however, drawing off the flood-tide in its progress up the river, and secondary channels diverting a portion of the ebb from the navigable channel, may be advantageously shut off, so as to concentrate the flood and ebb into the main channel. In a wide, winding tidal river, the ebb and flood tides tend to form different low-water channels, for the ebb-tide follows the course of the current of a non-tidal river close along the concave banks, crossing over from one bend to the next; whereas the flood coming up in the reverse direction, assumes a straighter course between the bends. The main low-water channel is that of the ebb, and is continuous; whereas the flood-tide channel terminates abruptly at low water at its up-stream end. This divergence of action reduces the available depth of the river; but longitudinal training-walls would have to be brought unduly close together between the bends to make the two channels coalesce. Dipping cross-dykes suitably placed in the bed of the river, and not raised above the shoals, would probably prove the most effective method of directing the two channels into one, for dredging through the shoal separating them could only furnish a temporary remedy.

Training the River Maas from Rotterdam to the Sea.

The outlets of the Rhine and the Maas, intersecting the southern part of Holland by a number of branches, present a great similarity to the deltas of rivers flowing into tideless seas; but they differ from delta channels in two important particulars. In the first place, there is a distinct rise of tide in the North Sea in front of these outlets; and this rise, though small, averaging about 5½ feet at the mouth of the Maas, flows some distance up these branches, which have very little fall as they traverse very flat low-lying land. A rise of tide, however, does not necessarily prevent the formation of a delta, with its accompanying obstacles

to navigation, as exemplified by the deltas of the Ganges and Irrawaddi, where the great volume of fresh water charged with alluvium overpowers the tidal flow. The large expanse of flat alluvial soil, moreover, and the numerous channels at the outlets of the Rhine and Maas, indicate that at some former period these rivers protruded a delta into the North Sea. The sea, however, at the present time, tends to encroach upon the coast-line of the ancient delta, so that no accumulation of alluvium is taking place at the outlets. The Maas, accordingly, must be regarded as a tidal river; and the deterioration which has occurred in the northern outlets within the last two centuries, is attributable to the large reclamations that have taken place, and the tendency of the flow of the river to follow the southern outlets where the tidal range and scour are greater.

Training of the Scheur Branch, with New Mouth.—The works designed by Mr. Caland in 1858, and carried out in 1863–76, have been described in a previous Paper.[1] They consisted in regulating the river by longitudinal training-walls, with a gradually widening channel nearly to the sea; the cutting of a new channel across the Hook of Holland, to straighten, shorten, and deepen the outlet; the closure of the old outlet channel; and the construction of two nearly parallel fascine-mattress jetties, over a mile in length, in continuation of the new channel across the sandy foreshore into deep water, Fig. 12, Plate 2. These works provided a much shorter and deeper approach to Rotterdam than the circuitous channel by Hellevoetsluis and the Voorne Canal; but the maximum depth at high water over the bar at the entrance was barely 20 feet, in place of 23 feet which had been anticipated. As pointed out by the Author in 1882, this deficiency in depth must be attributed to the widening of the new cut having been left to the natural scour of the river, resulting in the deposition in the jetty channel of a large portion of the material secured from the cut, and also to the inadequate width of the new cut checking the influx of the tide, and the loss of a portion of the ebb-tide diverted into the Old Maas nearly opposite the Vlaardingen, through the channel giving access to the Voorne Canal.[2] The Author also expressed the opinion that it would be quite possible to remedy these defects, by "placing gates across the branch channel leading to the Voorne Canal, by enlarging the width of the new cut, and by removing the accumulations of sand between

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[1] Minutes of Proceedings Inst. C.E., vol. lxx. pp. 24–28, and Plate 3, Figs. 6, 7, and 8.

[2] *Ibid*, vol. lxx. pp. 26, 27.

the jetties by dredging." [1] The Dutch engineers in charge of the works appear to have held similar views, for, since 1882, works on these lines have been carried out, and are on the eve of completion.

Additional Works in the Scheur Branch of the Maas.—The improvement works for securing the requisite depth up to Rotterdam were commenced in 1882, by the construction of a low training-bank 220 yards to the north of the south jetty, thereby contracting the width of the jetty channel to that extent, Fig. 12, Plate 2. The new cut has also been gradually excavated to the proper width, to correspond with the narrowed jetty channel, and its banks protected by fascine works; and the adjacent channel above has been similarly widened. [2] Dredging has also been extensively used for deepening the channel between the jetties, and out to deep water. In 1886, the rectification of the narrow, curved channel near Maassluis was commenced, comprising excavation for widening, and modifications in the training-works. The width of the entrance to the Noordgeul, the branch by which a considerable volume of the ebb-tide escaped into the Old Maas, has been reduced from 1,070 feet to 230 feet, so that now most of the ebb current which flowed away by this branch is retained in the Scheur branch, and increases its scour.

Results of the Maas Training-Works.—These works have completed the improvement which the original works inaugurated, Fig. 13, Plate 2; and the value of the new waterway is manifested by the remarkable development of Rotterdam within recent years. The slightly diverging jetties, being kept low, offer no impediment to the complete filling of the river by the flood-tide, whilst directing the scouring action of the latter half of the ebb-tide. The training, moreover, of the river in a gradually enlarging channel, produces uniformity in the flow, and enables the ebb current, reinforced by the large fresh-water discharge, to maintain the depth attained by dredging. The minimum depth in the fairway, 330 feet wide, through the jetty channel and out to sea, which was 10 feet at low water during 1882, was increased to $23\frac{2}{3}$ feet by 1891. The maximum draught of the vessels which could navigate the old route was $16\frac{3}{4}$ feet; and the journey between Rotterdam and the sea generally occupied eighteen hours. In 1882, vessels with a maximum draught of $19\frac{1}{3}$ feet could get up to Rotterdam by the new channel; whilst vessels drawing 25 feet could go to Rotterdam in 1888, and there is now a fairway to sea

[1] "Rivers and Canals," L. F. Vernon-Harcourt, p. 277.

[2] "Amélioration de la Voie Fluviale de Rotterdam à la Mer," J. W. Welcker. Vme Congrès International de Navigation intérieure, Paris, 1892.

beyond the jetties, 420 feet wide, with a minimum depth of 28¼ feet at high tide. Vessels, moreover, can now reach Rotterdam from the sea in two hours. No vessel drawing 23 feet got up to Rotterdam before 1886, whilst 95 came up in 1891; and whereas the number of vessels of 18 feet draught navigating the Scheur branch was only 65 in 1882, it rose to 1,245 in 1891. Altogether, between 1879 and 1891, the number of vessels trading with Rotterdam increased from 6,950 to 9,460; and the total tonnage was more than doubled in the same period.

The total cost of the works, from 1863 to the close of 1893, has amounted to about £2,935,000.

Training-Works at the Mouth of the Adour.

Former Condition of the Adour Outlet.—As the mouth of the Adour is close to the angle formed by the coasts of France and Spain, in the innermost recess of the Bay of Biscay, where deep water approaches the shore, it is exposed to the full force of the violent seas which beat upon that coast, especially during north-westerly gales. The waves constantly tend to heap up the beach in front of the mouth of the river, which is only partially prevented by the ebbing tide and the fresh-water discharge; so that formerly, like the River Yare in Norfolk, the outlet of the Adour shifted considerably at times, having been diverted 18½ miles to the north of its present position about the year 1450. The river was brought back to a straight course in 1579, by cutting a new channel between Bayonne and the sea, and barring the existing channel, which afforded a much improved depth over the bar; but the channel was soon deviated to the south by the travel of sand and gravel from the north, and the depth at its outlet deteriorated.[1]

Training-Works.—At length, in 1731–41, the outlet channel was fixed by high solid masonry training-walls on each side, 900 feet apart, which temporarily increased the depth over bar to 20 feet at high tide; but soon the bar formed again further out, where the issuing current lost its scouring influence. With a view of increasing the scour over the bar, the outlet-channel was gradually narrowed and prolonged by low training-works; but though the outlet remained fairly stable, the bar and the coast-line merely progressed seawards with the training-works.

In 1859, the training-works were again prolonged by partially open timber jetties, resting on rubble mounds raised to within

[1] "Ports Maritimes de la France," vol. vi. p. 936.

6½ feet of low water; and on the impending destruction of the timber-work by the sea-worm, iron cylinders, 6½ feet in diameter, sunk by compressed air, were adopted in 1867, and eventually replaced the timber jetties;[1] and they are now being slowly extended seawards, the southern jetty having been prolonged 200 feet since 1881, Figs. 14 and 15, Plate 2. Intervals of 10 feet have been left between the cylinders, which were originally intended to be closed by sliding panels whenever it might be expedient to concentrate the current; but these panels were costly, difficult to work, and wore out rapidly, so that at present, the cylinders and the low rubble base on each side, alone direct the current.[2] The openings were left in the jetties with the object of preventing the progression of the foreshore.

Results of the Adour Training-Works.—The increase in the minimum depth over the bar produced by the jetties, as compared with the depth in 1857, has generally varied between 1½ and 2½ feet, though it occasionally has attained 4 feet. Thus the minimum depth over the bar, at high-water spring-tides, was 17⅓ feet in 1869–70, 18¾ feet in 1861 and 1885, 20 feet in September 1886, and 17 feet in July, 1892, in place of 15¾ feet in 1857, the rise of ordinary spring-tides above the lowest low-water being 10 feet 10 inches, Fig. 16, Plate 2. The foreshore, however, has advanced, especially upon the north side, Figs. 14 and 15, Plate 2; the bar has moved a little further out; and the sandy beach, coming through the open jetty from the north, has encroached upon the jetty channel. The most important benefit, accordingly, effected by the training-works, consists in securing the stability of the outlet of the river. The increase in depth, however, at the mouth, though moderate aad variable, and the extension of the port of Bayonne, have been accompanied by a steady increase in the trade of the port, the total tonnage of exports and imports having risen from 147,800 tons in 1877, to 555,600 tons in 1892, a remarkable development in the foreign imports having commenced in 1883. Vessels of 2,100 tons, drawing 18 feet of water, have come up to the port within recent years, for a deeper channel generally exists to the south of the bar, whose crest is sometimes directly in front of the jetty channel, as was the case in 1892. The increase in depth over the bar, moreover, not only ensures a deeper entrance channel, but also reduces the surf on the bar, and therefore diminishes one of the perils of the approach.

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[1] Minutes of Proceedings Inst. C.E., vol. lxx. Plate 3, Fig. 5.

[2] "Les Jetées à Claire-Voie de l'Embouchure de l'Adour," A. Stœcklin, Congrès International des Travaux Maritimes, Paris, 1889, p. 6.

Disadvantages of the Design.—The comparatively small improvement in depth achieved by the jetties, must be attributed in some measure to the system adopted. As pointed out in a previous Paper,[1] the narrowing of the outlet-channel, from a width of about 1,000 feet above, to 550 feet between the jetties, in a river with a small basin and a fair tidal rise at the mouth, was a mistake, for it necessarily checks the tidal influx, and consequently lessens the discharge on the ebb. The rise of spring-tides, indeed, is actually, on the average, about 4 feet less in the river than in the sea outside, of which only $1\frac{1}{3}$ foot is due to the slope of the low-water line; so that $2\frac{2}{3}$ feet of tidal rise are excluded from the river by the works, equal to over a fourth of the tidal range. The open jetties, moreover, at the seaward end of the training-works, cannot direct the ebb current like solid banks, and enable the foreshore to protrude into the jetty channel without arresting its advance.

Better results would doubtless have been obtained by gradually enlarging the width between the training-works from Bayonne to the sea, so as to admit the full volume of tidal water into the river, and by extending the works beyond the bar, which could then have been lowered by dredging. In view, however, of the exposure of the site, a more sheltered entrance could have been provided by constructing two breakwaters, starting wide apart from the shore, and converging towards the outlet beyond the bar, in place of the jetties, which though more costly would have maintained the depth better at the outlet. The experience of solid structures projecting from the coast, at the mouth of the Maas, Ymuiden, Tynemouth, and elsewhere, indicates that the shore-line, though advancing at first, reaches a position of equilibrium before approaching the ends of the piers.

Training the River Nervion from Bilbao to the Sea.

The River Nervion, which affords the port of Bilbao access to the sea, has only a small drainage-area, and enters the Bay of Biscay though a small bay, which, enlarging to a width of about 3 miles at its outlet and facing north-west, is exposed to the full force of the Atlantic waves rolling in from that quarter, so that vessels do not anchor in the bay except in the finest weather. The mouth of the Nervion, accordingly, is subject to conditions very similar to those of the mouth of the Adour; and the sea formed a bar across its mouth, over which, in 1878, there was a maximum

[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 20.

depth of only $3\frac{3}{4}$ feet at the lowest low-water, $10\frac{2}{3}$ feet at high water of the lowest neaps, and $18\frac{1}{3}$ feet at high water of equinoctial springs, the tidal range being 9 feet at a mean tide, and $14\frac{3}{4}$ feet at equinoctial springs, Figs. 17 and 18, Plate 2. Moreover vessels drawing more than 9 feet could not go up to Bilbao, which is about $8\frac{1}{2}$ miles from the mouth of the river. Sea-going vessels consequently were obliged to load and discharge at Portugalete close to the mouth of the river, thereby greatly impeding the trade of Bilbao, which nevertheless tended to increase, owing mainly to the large export of iron ore.

Regulation and Training of the River Nervion.—The first work for improving the river below Bilbao was commenced in 1878, and

Fig. 19.

Scale $\frac{1}{2400}$.

CROSS-SECTION OF RIVER NERVION AT C C ON PLAN.

Fig. 20.

Scale $\frac{1}{2400}$.

CROSS-SECTION OF RIVER NERVION AT B B ON PLAN.

Fig. 21.

Scale $\frac{1}{2400}$.

CROSS-SECTION OF RIVER NERVION AT A A ON PLAN.

consisted in the substitution of a straighter channel for a very sharp bend in the river just above the confluence of the River Cadagua, which, running close under Monte Cabras, was the cause of frequent accidents to the shipping. The new channel was excavated across the bend away from the hill, and was guided and protected by training-works on each side [1]; and the abandoned portion of the old channel was filled up, the work being completed in 1883, having comprised a good deal of excavation in rock, dredging, 400 yards of quay-wall, and other works, Fig. 17, Plate 2, and *Fig. 21* above. New works for the systematic improvement of the river from Bilbao to

[1] "Memoria sobre el Progreso y Adelanto que han tenido las Obras de Mejora de la Ria de Bilbao, 1879–80," E. de Churruca.

the bar were commenced in 1880. They consisted in the regulation of the river at awkward bends, and along wide reaches, by training-works and dredging, Fig. 17, and *Figs. 19* and *20*; the formation of river quays; and the concentration of the scour of the ebbing current by the prolongation of the old Portugalete jetty on the west side of the mouth, for about 880 yards, with a slightly concave bend towards the channel, out beyond the bar into a depth of 3 fathoms at the lowest low-water,[1] Figs. 17 and 18, Plate 2. These works are now completed, the river having been trained in a gradually enlarging channel from Bilbao to the bar, thereby ensuring the free admission of the tide. The extension of the jetty, carried out in 1881–91, has been built, for the inner 620 yards, of a concrete wall, founded at low-water level on a rubble

Fig. 22.

Scale $\frac{1}{1500}$.

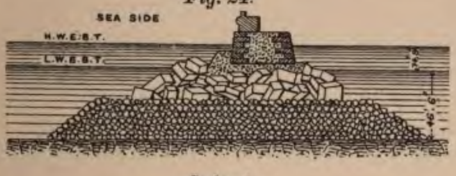
SECTION OF JETTY AT MOUTH OF RIVER NERVION.

Fig. 23.

Scale $\frac{1}{1500}$.

SECTION OF JETTY AT MOUTH OF RIVER NERVION.

Fig. 24.



Scale $\frac{1}{1500}$.

SECTION OF BREAKWATER AT MOUTH OF RIVER NERVION.

mound rising to within a foot of the highest high tide, and surmounted by an open viaduct resting on screw piles, which gives access to the solid pier-head protected by a parapet, *Figs. 22* and *23*.

It is proposed to shelter the inner portion of the exposed bay into which the River Nervion flows, by two breakwaters projecting from the coast on each side, and situated so as to form a sheltered entrance facing the north-east shore of the bay, in an average depth of 7 fathoms, Fig. 17, Plate 2, and *Fig. 24*. The south-

[1] "Memoria que manifiesta el Estado y Progreso de las Obras de Mejora de la Ría de Bilbao, 1888–89 y 1890–91," E. de Churruca; and Anales de Obras Publicas, vol. xi., Madrid, 1883.

western breakwater is in progress,[1] and when the works are completed, a much needed sheltered anchorage-ground and approach to the river will be provided for vessels trading with Bilbao, as well as a harbour of refuge.

These works as a whole present some resemblance to the River Tyne improvement works, in the training of the river and the outer harbour. The River Nervion, however, has not been systematically deepened by dredging like the Tyne; whilst its bar has been lowered without the protection of the breakwaters outside. Nevertheless, though these breakwaters do not constitute an absolutely essential portion of the river improvement works, they will be very useful in preventing the drift of the beach across the outlet of the river, and in protecting the mouth from the heaping-up action of the waves.

Results of the Nervion Training-Works.—The regulation and training-works, aided by dredging, have formed a channel with a minimum depth of about 12 feet at the lowest low-water, and 27 feet at the highest springs, from the sea up to Bilbao; and the depth over the bar has been increased nearly 12 feet, Fig. 18, Plate 2. This has been accomplished at a cost of about £412,000; though additional expenditure has been incurred in buoying, electric lighting, cranes, and dredging the Axpe basin, as well as the breakwater in course of construction.[2]

The trade with the port exhibits a considerable increase since the commencement of the works, the exports and imports having risen from 1,340,400 tons in 1878–79, to 4,519,170 tons in 1891–92, a maximum of 5,038,400 tons having been reached in 1889–90. Whilst, however, the increase in imports, from 144,977 to 754,568 tons, has been fairly steady, the main increase in the exports, from 1,195,422 to 3,764,604 tons, was reached in 1882–83.

Comparison of the Nervion with the Maas.—The width of the trained channel of the Nervion is only about a quarter of that of the Scheur branch of the Maas, which is drawn to half the scale of the Nervion and of the Adour on Plate 2 on account of its much greater size. The principles, however, on which the works were designed were similar in the two cases; and the execution of the works has been attended in both rivers with very satisfactory results, Figs. 13 and 18, Plate 2. The much smaller freshwater discharge of the Nervion has been compensated for by a larger

[1] "Memoria que manifiesta el Estado y Progreso de las Obras de Mejora de la Ria de Bilbao, 1891–92," E. de Churruca, Plate.

[2] "Memoria que manifiesta el Estado y Progreso de las Obras de Mejora de la Ria de Bilbao, 1891–92," E. de Churruca, pp. 16, 17.

tidal rise, and a steeper sea-slope in front of its outlet. The exposure of the mouth of the Nervion is considerably greater than that of the Scheur branch outlet; and though the Nervion outlet is not situated so directly on the coast of the Bay of Biscay as the Adour, much of the greater success achieved by the training-works on the Nervion must be attributed to their closer accordance with the principles that should regulate the improvement of tidal rivers than the works of the Adour.

4. Training-Works in Tidal Estuaries.

In training the outlet-channel of a tidal river through a sandy estuary, the maintenance of the tidal capacity by the free admission of the tide, and its increase by the lowering of the low-water line, have equally to be aimed at, as in the case of a tidal river flowing straight into the sea. The existing channel, however, of an ordinary tidal river affords some indication of the suitable width and rate of enlargement of the trained channel; whereas a wide irregular estuary furnishes no evidence of the enlargement seawards requisite for the trained channel of a river through it. Nevertheless, some guidance may be derived from the rates of enlargement of the estuaries of rivers possessing good outlet-channels, and from tidal rivers trained with satisfactory results. Though the rate of enlargement, even in tidal estuaries possessing the best channels, is irregular, it appears to range on the average between 1 in 90 and 1 in 30, being more rapid in the high-water channel than in the low-water, increasing on approaching the sea, and becoming very rapid close to the outlet.[1] The rate of enlargement in the trained channel of the Maas, between Schiedam and the mouth, averages about 1 in 77, of the Clyde from Renfrew to Dumbarton 1 in 71, and of the Tyne from Newcastle to its mouth 1 in 74. This rate should vary in proportion to the rise of tide, and the distance to which the tide is propagated up the river; but probably in most cases the suitable rate of enlargement seawards would be found to lie, on the average, between 1 in 80 and 1 in 40, with a more rapid widening near the outlet.

Rivers have generally been trained through estuaries in a comparatively narrow channel, in order that, whilst fixing the previously wandering channel, its depth may be increased by scour; and it has been assumed that these training-works would

[1] "The Physical Conditions affecting Tidal Rivers, and the Principles applicable to their Improvement," L. F. Vernon-Harcourt, Manchester Inland Navigation Congress, 1890, p. 10.

produce no alteration in the tidal capacity of the estuary outside the trained channel. The training-walls, moreover, have been raised to half-tide level or higher, to ensure an adequate scour in the channel; whilst it has occasionally been supposed, as in the case of the Ribble, that the scour produced by training-walls, terminating at some distance from deep water, would suffice to form a good channel out to sea.

If no alluvium was brought in by the flood-tide, or carried down by the river, training-works through an estuary would produce wholly beneficial results, provided they did not at all check the inflow of the tide; but unfortunately this is not generally the case. The flood-tide usually enters an estuary charged with alluvium stirred up by waves from sandbanks, or eroded from the beach and cliffs; and large rivers of a torrential character commonly bring down considerable quantities of material from inland. Accordingly, most estuaries only remain in their approximate state of equilibrium so long as their natural condition is not interfered with; and their wandering channels, though impediments to navigation, stir up periodically and disperse the accretions which would otherwise accumulate, and would reduce the tidal capacity of the estuary. Directly training-works are introduced, the existing equilibrium is disturbed by the fixing of the shifting channel, which concentrates the main tidal flow and ebb into the trained channel, and leads to deposit of sediment in the slack water at the back of the training-walls, and even at the sides of the estuary in advance of the walls, resulting eventually in a considerable reduction in the tidal capacity of the estuary at the sides of the trained channel, which is only very partially compensated for by the lowering of the low-water line in the channel itself. These considerations show how vital to the due maintenance of the outlet is the correct enlargement of the trained channel through an estuary, to which hitherto too little attention has been paid. Experience, moreover, has proved that the deepening effects of training-works extend very little beyond their extremities; and therefore it is essential for securing a good channel to the sea to prolong the training-walls to deep water.

The River Weser furnishes an instance of training-works constructed systematically along a tidal river, in which the rate of enlargement of the channel has been determined with special care with very satisfactory results, and where the training-works are being extended into the estuary. The River Loire illustrates the influence that training-works may have, under certain conditions, in deteriorating the estuary below them, by the deposit

of material brought down by the river. Lastly, the Seine estuary exhibits the results of forming a narrow trained channel in a wide estuary into which the flood-tide brings large quantities of alluvium, and of terminating the training-walls some miles short of the open sea.

Training-Works in the Lower Weser.

The River Weser drains an area of 18,600 square miles, and has a total length of 440 miles, including the course of the Werra; though the name Weser is confined to the portion of the river below Münden, formed by the confluence of the Werra and the Fulda. Bremerhaven is situated at the head of the estuary, through which the river flows into the North Sea about 36¾ miles distant, Fig. 25, Plate 3. The tidal influence formerly disappeared at Bremen, 42 miles above Bremerhaven where the average rise of tide is 10 feet 10 inches, the tidal rise at Heligoland, beyond the combined estuaries of the Elbe, the Weser, and the Jade, being only 6 feet.[1] The average fresh-water discharge of the Weser at Bremen is 387 cubic yards per second, the summer low-water discharge 196 cubic yards, and the maximum flood discharge about 5,200 cubic yards per second.

Training-Works and Dredging in the Weser.—The works which have been carried out from Bremen to Bremerhaven since 1887, under the direction of Mr. Franzius, consist in training the river by fascine mattresses in straightened high-water and low-water channels, progressively increasing in width seawards in the form of a trumpet, and dredging between the training-walls, so as to obtain an increased depth, Figs. 25 to 29, Plate 3, and *Fig. 30.* In carrying out the training-works, bends have been eased and double channels suppressed, so as to facilitate the tidal flow and ebb, and to concentrate the waters in a single channel. The width of the low-water channel has been made sufficiently large to allow of the free passage of the current in it from a little before to a little after low-water, without being wide

Fig. 30.

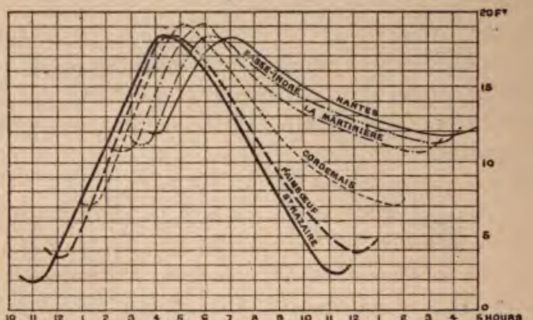
Scale $\frac{1}{400}$.

TRAINING-WALL, RIVER WESER.

[1] "L'Amélioration des Fleuves dans leur partie maritime," L. Franzius, V^me Congrès International de Navigation intérieure, Paris, 1892.

very irregular, varying at Nantes between the extreme limits of 160 cubic yards per second in dry years, and 7,600 cubic yards per second in exceptional floods; and it brings down large quantities of heavy alluvium, mainly eroded from its banks. Owing to its deficiency in depth for long periods during dry weather, the river is very little used for navigation above Nantes, though its lateral canal between Roanne and Briare accommodates a large traffic. The tide really extends up to Mauves, 9⅓ miles above Nantes; but Nantes is regarded as the boundary between the lower and the tidal Loire.[1] The rise of tide at St. Nazaire, at the mouth of the Loire, is 16½ feet at springs and 7⅔ feet at neaps, *Fig. 34*, which is reduced at Nantes to 6 feet at springs and 3⅕ feet at neaps during a low stage of the river; but during average floods of the river, the tide only reaches Le Pineau below

Fig. 34.



TIDAL DIAGRAM, SPRING-TIDES, RIVER LOIRE, 1876.

La Martinière, and in very great floods the flood-tide current is only found near the bottom at St. Nazaire. The alluvium in the channel above low water consisted formerly of marine deposits up to Basse-Indre, and of sediment brought down by the river higher up.

Training-Works below Nantes.—Proposals for improving the Loire, in order to render Nantes accessible for large vessels, were made as early as the seventeenth century; but the first works were carried out in 1756–68, previously to which vessels of 8-feet draught reached Nantes with difficulty. These works comprised the barring of the secondary channels between the various islands and the left bank, by submerged rubble dams, from Bouguenais down to Couëron, so as to concentrate the main current in the

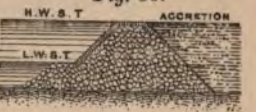
[1] "Ports Maritimes de la France," vol. v. p. 242.

channel passing near the right bank, with the object of increasing its depth.[1] Groynes, also, were constructed, projecting into the channel along the right bank, with a view of further contracting the waterway and concentrating the current. Considerable accretions, however, resulted from these works, and no material improvement in depth was effected.

No further works were executed until, in 1834–40, longitudinal training-walls were constructed in places between Nantes and Le Pellerin, generally along one side only, so as to narrow the width of the channel to between 820 and 1,000 feet, and raised to $3\frac{1}{4}$ feet below high water of spring-tides. Even these works, however, produced only a very slight improvement in the channel, the increase in depth over the shoals by 1850 amounting merely to from 8 inches to 1 foot.

Longitudinal training-walls were again carried out in 1859–65, between Nantes and La Martinière, for a distance of 10 miles. These training-walls, placed on each side of the channel, were formed of rubble mounds pitched on the face and raised to the level of high water of low spring-tides, Fig. 35, Plate 3, and *Fig. 36*; and the width between them, of 650 feet at the upper end, was increased gradually to 1,000 feet at Le Pellerin, a rate of enlargement of about 1 in 136, Fig. 35. The increase in depth effected by these works was only gradually obtained, having reached an average of 5 feet over the whole length in 1876, and $3\frac{1}{4}$ feet over the shallowest places, Fig. 37, Plate 3; the average depth in the navigable channel between the training-walls having been 20 feet, and the minimum depth $14\frac{3}{4}$ feet at high-water spring-tides in 1876, before the commencement of dredging. The shoals are found in places where the old training-walls have been unaltered, or where side channels have been left open for riparian traffic; and they might be lowered by the completion of the training-walls along the old walls, and across the gaps.

Fig. 36.



Scale $\frac{1}{400}$.

TRAINING-WALL, RIVER LOIRE.

The deepening of the trained channel was unfortunately attended by a large extension of the sandbanks in the estuary below, between La Martinière and Paimbœuf; so that this section of the river, which was previously deeper than the portion above, fell into a worse condition, Figs. 33, 35, and 38. This de-

[1] "Ports Maritimes de la France," vol. v. p. 257.

terioration was due to the deposit in this part of the estuary of the material scoured out of the trained channel, to the loss of tidal scour by the large accretions which have taken place at the back of the training-walls, and to the direct discharge of the alluvium brought down by the river into this section of the estuary. The mean depth of the navigable channel through this part of the estuary was reduced from $20\frac{1}{7}$ feet, before the construction of the training-walls, to 18 feet in 1876; and the length of the shoals over which the depth was under $17\frac{1}{3}$ feet was doubled in the same period, whilst fresh islands have been formed, or are in course of formation.

Ship-Canal alongside the Loire Estuary.—As the training-works between Nantes and La Martinière, though improving the depth in the trained channel, failed to afford Nantes a good channel to the sea, proposals were made to secure the requisite depth below La Martinière by prolonging the training-works, and also by a lateral ship-canal. Eventually, in 1879, it was decided to avoid the shoaling circuitous channel through the upper portion of the estuary below the training-works, by forming a ship-canal through the land on the left bank, from La Martinière to Carnet, $4\frac{1}{3}$ miles above Paimbœuf, where a deep channel exists between Carnet Island and the left bank of the estuary, Figs. 35 and 37, Plate 3. This canal was completed in 1892; it has a length of $9\frac{1}{3}$ miles, a bottom width of $78\frac{3}{4}$ feet, and a depth of water of $19\frac{2}{3}$ feet; and it is closed at each end by a lock, 558 feet long and 59 feet wide.

Dredging in the Loire Estuary.—Since 1877, the yearly expenditure on dredging in the estuary has been £12,000, in place of £1,600 previously, the dredging having been mainly carried on, up to 1892, in the shallow portion of the estuary between La Martinière and Paimbœuf, Fig. 38, Plate 3, increasing the available depth at spring-tides in this portion of the navigable channel from 13 feet to $15\frac{3}{4}$ feet. In 1892, in view of the approaching opening of the ship-canal, the expenditure on dredging was increased to £22,100 for the year, with the object of gradually deepening the trained channel above the ship-canal to about 21 feet below high water of spring-tides, and the channel below the outlet of the ship-canal to about 24 feet out to deep water. The dredging in the section of the estuary superseded by the ship-canal, though reduced in yearly volume, will still be continued to a moderate extent, in order that the tidal influx may not be impeded, and that small vessels may get up to Nantes without having to pass through the ship-canal. The influence of the increased depth obtained by

dredging is indicated by the increased maritime trade of Nantes, the tonnage of its exports and imports having risen from 358,500 tons in 1878 to 459,100 tons in 1892.

By means of the ship-canal and dredging, vessels of 16½ feet draught will be able to reach Nantes from the sea in a single tide, even at the lowest neaps, which formerly was only possible on barely fifty days in the year; and vessels of 19 feet draught will be able to accomplish the passage during spring-tides and in flood-time.

Remarks on the Loire Estuary.—The estuary of the Loire is unfavourable for improvement by training-works, owing to the large quantities of sand brought down by the river during floods, which, together with alluvium brought in from the sea, readily deposits at slack-tide in sheltered parts of the estuary. The training-walls concentrated the discharge of the river detritus in the portion of the estuary below them, and at the same time reduced the tidal scour in this part by causing a diminution of tidal capacity above by the accumulation of deposit behind them. The necessity of eventually prolonging the training-works down to Paimbœuf, if a navigable channel through the estuary was to be provided for Nantes, should have been contemplated at the outset; and the enlargement of the width of the trained channel down to La Martinière should have been made greater. The training-works actually constructed merely shifted the position of the worst channel lower down the estuary, which has now been abandoned for the ship-canal. Dredging, however, will always be needed in this portion of the estuary, to an extent sufficient to remove all the sediment brought down by the river, otherwise the reduction in tidal capacity produced by this deposit, by diminishing the tidal scour in the lower estuary and at the outlet, would produce a reduction in depth both above and below St. Nazaire. With the large port of St. Nazaire at the mouth of the Loire, and a bar outside, it would be inexpedient to carry out works which would impair the efficiency of the estuary as a scouring reservoir, and thereby shoal the approach of St. Nazaire. If there was no port at the mouth of the estuary, the river might have been advantageously trained from Nantes, in a channel gradually expanding to the full width of the contracted estuary at Paimbœuf, and its depth increased by dredging, for the depth over the bar outside is greater than the general depth in the channel through the estuary.

Training-Works in the Seine Estuary.

A full description was given by the Author in 1886 of original condition of the estuary of the Seine, and of the char produced by the training-works carried out, in 1846–69, from Mailleraye to Berville.[1] It was pointed out that these train works, whilst greatly improving the channel between then, led to large accretions both behind the walls, and also at the of the estuary for some miles in advance of the ends of the w and that their influence on the depth and stability of the cha ceased a very short distance beyond their termination. T accretions, unlike those in the upper estuary of the Loire almost wholly due to the materials washed by the sea from coast of Calvados and brought in by the flood-tide, which re deposit in any sheltered areas in the estuary during slack-tid the Seine brings down very little alluvium from inland, and fore is free from one of the disadvantages to which the Lo exposed. The training-works, even in their incomplete state proved a very great advantage to Rouen, which they converted into a sea-port, by removing the obstacle of 28 miles of shallow and shifting channel, and by extending water in the river down to Berville, within about 10 miles sea, so that vessels can take advantage of the good rise of t the estuary for the passage between the sea and the trained ch The exports and imports of Rouen, which had already re 1,026,100 tons in 1878, only nine years after the completion training-walls, have now risen to 2,062,300 tons in the year

Deficiencies in the Seine Training-Works.—Notwithstandin greatly improved access to Rouen effected by these training- they are defective in some respects. In the first place, the enlargement of the trained channel, of 1 in 200, is inad especially considering that practically the high-water cha confined to the width between the training-walls. Second large accretions in the estuary resulting from the previously noted,[2] which appear not yet to have reached limit, have considerably reduced the tidal flow and ebb t the outlet, to the prejudice of the maintenance of the full Lastly, a shallow, tortuous, shifting channel still exists for 1 below the training-walls, which can only be deepened, straig

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv. pp. 241–52, and and 5.

[2] *Ibid*, vol. lxxxiv. pp. 246, 254–257.

and made permanent by a prolongation of the training-works. The insufficiency of the enlargement is now fully realised; and a widening of the trained channel below Quillebeuf or Tancarville has been introduced into most of the schemes proposed for the completion of the training-works.

Alterations in the Seine Estuary.—The accretions in the estuary, which up to 1875 were mostly confined to the spaces at the back of the training-walls, have, since the filling up of these spaces, extended down to Harfleur on the right bank, and Honfleur on the left bank, 8½ and 5¼ miles respectively below the ends of the training-walls. The concentration of the currents by the training-walls, and by the deepening of the channel between La Mailleraye and Berville, appears to have exercised a beneficial influence upon the depths at the outlet at first, for the charts exhibit an advance of the 5-metre and 10-metre lines of soundings into the estuary up to 1875. Since then, however, these lines of soundings have receded, so that in 1891 they were 3 and 3⅛ miles respectively seawards of their position in 1875, and further out than in any previous chart back to 1834. This shoaling at the outlet during sixteen years is probably the result of the reduction of tidal scour by the large accretion which has occurred below the training-works since 1875. The outlet-channel through the estuary, as shown on the chart of 1891, after winding past Honfleur, was very nearly barred at low water between the Amfard and Ratier banks.

Schemes for the Prolongation of the Seine Training-Walls.—It is now generally admitted in France that a prolongation of the training-walls is necessary for remedying the unsatisfactory condition of the outlet-channel of the Seine; but the choice of lines on which this prolongation should be made has given rise to a variety of schemes, exhibiting a wide difference of opinion as to the principles on which a tidal river should be trained through a wide sandy estuary. Some only of the schemes were given in the Paper on the River Seine,[1] already alluded to, which had been proposed up to 1885; and since then others have been presented. Briefly, these schemes may be divided into three types, namely—(1) The formation of a more or less enlarging trumpet-shaped channel between Tancarville and the outlet; (2) Training the enlarging channel through the estuary in a sinuous form, terminating in some cases short of Honfleur; and (3), Barring nearly four-fifths of the outlet by a breakwater from Villerville to the Amfard bank, and training the channel inside the estuary by one or two walls.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv. pp. 247–251, and Plate 4, Fig. 9.

The first type follows the dictates of experience, in endeavouring to guide the channel whilst freely admitting the flood-tide; the second aims at securing stability in the channel by a succession of curves, as in a winding non-tidal river, where the deep channel follows the concave banks; and the third converts the estuary into a sluicing basin, to ensure a strong scour, and consequently a deep channel through the restricted outlet.

In the first type, the symmetrical form of the trained channel tends to regulate the course of the low-water channel; but it is difficult thereby to fix and deepen the low-water channel adequately without unduly reducing the width between the training-walls. The deepening and regulation, however, effected by the training-works might be assisted advantageously by dredging, or might be completed by training the low-water channel by supplementary inner low-water training-walls, or dipping cross-dykes carried out on each side from the training-walls to the edge of the low-water channel, which at high water becomes the main navigable channel.

The theory of the stability and deepening of the channel being secured by a sinuous course is based upon the erroneous assumption that the flood and ebb tides follow the same course, like the downward current of a non-tidal river. The ebb current does, indeed, follow the same course as the ordinary discharge of a river; but the flood-tide, in a wide channel, adopts a straighter course, and attempts to form a separate low-water channel, as is amply apparent in the sandy bed of a wide tidal river at low water.

A great reduction in the width of the outlet of an estuary diminishes the tidal rise inside, by checking the tidal influx, and is thereby prejudicial both to the depth and maintenance of the river above. Moreover, if the rapid flood-current through the narrowed opening brings in any sediment, this matter will readily deposit when the velocity of the current is greatly reduced on expanding over the wide estuary inside, and the tidal capacity of the scouring basin will be gradually diminished.

Experiments on Training-Walls with Working Models.

On the appearance of fresh schemes for the prolongation of the Seine training-walls subsequent to the reading of his Paper on the River Seine, the Author felt convinced that no arguments could ever satisfactorily decide between such divergent opinions, and determined to resort to the test of experiment with a working model of the tidal Seine. The results of these experiments have been published

elsewhere,[1] and they confirmed precisely the view stated above. The reduction of the outlet of the estuary by a breakwater in the model, diminished appreciably the minute tidal rise obtainable, and resulted in the gradual silting-up of the estuary, as well as large accretions outside the breakwater, and opposite Trouville in the model. The sinuous training-walls gave double and very defective channels in the model; and the only satisfactory results were obtained by the trumpet-shaped channel, which, doubtless, would have been greatly improved by inner training-works at low-water level, or by dredging. The French Government engineers are now carrying out a series of similar experiments at Rouen with a much larger model of the tidal Seine, as urged by the Author at the Frankfort Congress in 1888, after describing the results already achieved by his experiments then in progress.[2] It may be hoped that these experiments, conducted on behalf of the French Government, when completed will still further elucidate the principles of training rivers through tidal estuaries, which the Author has endeavoured to deduce from his own experiments,[3] and that they will lead to a successful completion of the Seine training-works.

Experiments on training-walls with a model of the Mersey estuary have also been described elsewhere,[4] and the results were referred to by the Author in his remarks on the Paper by Mr. G. F. Lyster, M. Inst. C.E., on "Recent Dock Extensions at Liverpool."[5] They indicate that in the case of a wide inner estuary separated by a narrow neck from an outer sandy estuary, training-works may be injurious in the inner estuary, and beneficial in the outer estuary in prolongation of the neck. They, moreover, show that a prolongation of the Birkenhead shore by a training-wall carried out beyond New Brighton into Liverpool Bay, by barring the Rock channel, would direct the tidal currents more powerfully across the Mersey bar, and thereby improve and maintain the deepening effected by the dredging on the bar.

The Author is convinced, from the results of his experiments,

[1] Proceedings of the Royal Society of London, vol. xlv. p. 504, and Plates 2–4; and "Amélioration de la Partie Maritime des Fleuves y compris leurs Embouchures," L. F. Vernon-Harcourt, V^{me} Congrès International de Navigation intérieure, Paris, 1892, p. 24.

[2] III Internationaler Binnenschifffahrts-Congress zu Frankfurt-am-Main, 1888, Verhandlungen, p. 195.

[3] Proceedings of the Royal Society, vol. 45, p. 522.

[4] *Ibid.*, vol. 47, p. 142; "Effects of Training-Walls in an Estuary like the Mersey," London, 1890.

[5] Minutes of Proceedings Inst. C.E., vol. c. p. 56.

that working models would furnish most valuable assistance in deciding on the respective merits of various schemes for training-works in any particular estuary, or in designing a suitable scheme. Also, by the results of experiments with training-walls in models of estuaries of various forms, and subject to different physical conditions, the correct principles for training rivers through tidal estuaries, about which at present so much difference of opinion is manifested, might be definitely established.

Concluding Remarks.

The Author has much pleasure in acknowledging his obligations to Mr. Guillain, Director of Works at the Ministry of Public Works in Paris, for procuring information for him about the Rhone, the Loire, and the Adour, and for statistics relating to navigation, and to the engineers of those rivers for the information supplied, especially to Mr. Girardon for a detailed account and drawings of the Rhone training-works. He is also indebted to Mr. Welcker for a recent chart of the Scheur branch of the Maas, to Sir Charles Hartley for the chart of the Sulina mouth of 1891, and to Mr. Guérard for charts of the mouth of the Rhone of 1841 and 1891, from which the longitudinal sections of the Rhone bar have been made. He has also derived a good deal of information about the River Nervion from the yearly reports which Mr. E. de Churruca kindly sent him, about the Weser from a Paper by Mr. Franzius, and about the Volga from a Paper by Mr. V. E. de Timonoff, Assoc. M. Inst. C.E.

The Author has submitted this Paper to the Institution in the belief that, by comparing and contrasting the results of training-works in a variety of rivers subject to different physical conditions, the science of training rivers can be most effectually advanced, and the principles that should be followed in designing training-works can be best determined, aided in the case of tidal estuaries by experimental investigations.

The Paper is illustrated by tracings from which Plates 1, 2, and 3, and the *Figs.* in the text have been prepared.

(*Paper No. 2726.*)

(*Translated from the French and abridged.*)

"Estuaries."

By HENRI LÉON PARTIOT, Inspecteur Général des Ponts et Chaussées.

ESTUARIES are inlets on or near the sea-coast, containing banks which the tides successively cover and lay bare. They may be divided into two classes, namely: (1) Estuaries devoid of rivers; and (2), Estuaries into which rivers flow. Each of these classes, moreover, may be sub-divided into estuaries expanding to a wide outlet into the sea, and estuaries with a narrow outlet, formed either naturally by banks or the land, or artificially by protecting breakwaters.

1. ESTUARIES DEVOID OF RIVERS.

Funnel-shaped Estuaries.

These estuaries are generally found in the indentations of the coast, and vary considerably in form and extent. The materials which encumber them are brought in by currents and waves, or are formed on the spot by the erosion of the coast, and the gradual disintegration of this detritus. The rate of travel of these materials along the coast depends on the frequency and direction of the winds in the locality.

Formation of an Estuary.—Where an inlet exists on the coast, the waves tend to fill it with the shingle and sand they bring in; and a little estuary is thus formed in this creek. If the obliqueness of the prevailing winds is great enough, and the duration of winds normal to the coast small, the advance of the sandy beach closes the estuary before it is filled up. Being thus completely shut off from the sea, it is converted into a marsh, of which the marshes at Cayeux, near the mouth of the Somme, are instances. If the line of beach does not quite close the entrance, but leaves a passage for the tides, it protects the estuary, and forms a narrow outlet.

Dunes.—Besides the materials eroded from the coast, the waves carry along alluvium brought down to the shore by rivers; and often also the sea casts up sand from its bed, of which the coast of Gascony exhibits a striking instance. There the sandy bed of the ocean rises with a gentle slope towards the shore; and the waves raised by the prevailing westerly winds cast the sand upon the

shore, and the winds in their turn drive it inland. This is the origin of the long line of dunes which extend from the Gironde to Biarritz; and the shore, which was formerly intersected by numerous creeks, has now a straight line of sandy beach, 138 miles in length, which, under the influence of north and north-westerly winds, has closed the bays before they were silted up. These bays, into which only small streams flow, have consequently become pools and marshes, Fig. 1, Plate 4. The bay of Arcachon, however, into which the little river Leyre discharges, has become an estuary whose outlet is nearly closed by the shore-line. The sands had begun to fill up this vast bay, and the winds had formed some dunes near Andernos; and the travel of the sands along the shore, after pushing the outlet $3\frac{3}{4}$ miles to the south of Arcachon, has left this bay, which has a width of $6\frac{1}{4}$ miles, an opening into the sea only 1,100 yards wide. The dunes formerly progressed slowly inland like waves, invading the land and burying whole villages. Their progress was arrested at the beginning of the century, by fir plantations; but more recently Mr. Chambrelent succeeded in stopping the sand in front of the first dune, by forming a palisade of upright planks, with intervals of an inch between them, at the toe of the dune, about 400 feet from high water mark, which are raised by a lever as the dune rises against them, till, when the height of the dune attains 26 to 32 feet, this height and the steepness of the slope cause the sand to fall back towards the shore, where the winds drive it back into the sea. Thus an artificial dune is formed, with its steepest slope facing the sea, the reverse form to natural dunes. Sands mixed with silt or clay, being less affected by wind, do not form dunes.

Filling up of Funnel-shaped Estuaries.—Funnel-shaped bays devoid of rivers, and exposed to the inroad of sand, gradually fill up, the rate of accretion depending on the amount of sand provided by the coast or the bed of the sea. The deposit results from the slackening of the flood-tide in the bay on encountering any bank or the shore; and the bank or shore gradually extends seawards, this accretion taking place at the expense of banks nearer the sea, or actually in the sea. The silting up of the inner part of the bay entails eventually a shoaling of the lower part, and a reduction of the tidal water entering the bay, by which the depth of its channel and outlet have been maintained. Reclamations in the estuary produce the same results; and, therefore, artificial accretions at the mouth and in the tidal portion of rivers should be rarely

[1] "Les Landes de Gascogne," M. Chambrelent, Paris, 1887, pp. 92–94.

undertaken, and only with the utmost caution. The estuary of the Wash, and Vays Bay and Mont St. Michel Bay on the coast of Normandy, furnish examples of silting up.

Estuaries with Narrow Outlets.

The narrow opening, or neck, through which the tide enters some estuaries, may be very short, as at the mouth of the Gironde and of the Foyle, or may have a certain length, as in the Tagus and the Mersey. These estuaries would be exposed to the same external influences as the open estuaries just considered, if they were not protected by the narrowness of their outlet, which protection is attended by very important benefits to navigation.

Effect of a Neck.—All the water flowing in and out of these estuaries is obliged to traverse the neck; and instead of spreading out over a wide outlet, where the water which does not flow through the channel is lost to navigation, it is concentrated into a single passage, and, consequently, acts more powerfully on the bar and deepens the channel. These estuaries, moreover, are more sheltered from storms, for the waves are almost wholly stopped outside; whereas funnel-shaped estuaries are favourable to their propagation, and increase their height. The waters, also, at the farthest end of the estuary, reaching the neck near the end of the ebb, have a great effect in maintaining the depth of the channel. These advantages give a decided superiority to restricted outlets; whilst observation further demonstrates that deep channels exist both above and below the neck for a considerable distance. Thus the Jade estuary, in North Germany, with a length of about 10 miles and a width of $9\frac{1}{3}$ miles, has an outlet of only $3\frac{1}{10}$ miles, having a depth of 65 feet, the rise of tide at the mouth being $12\frac{3}{4}$ feet at springs, Fig. 2, Plate 4. Three channels stretch into the estuary inland of the neck, one having a depth of 33 feet for $4\frac{1}{3}$ miles, and the other two being $16\frac{1}{2}$ feet deep for about $1\frac{1}{8}$ and $2\frac{1}{3}$ miles respectively; whilst below the neck, a channel $17\frac{1}{2}$ miles long, with depths of from 33 to 82 feet, extends out to the sea. Poole harbour, on the south coast of England, has a length and width of $9\frac{1}{9}$ miles, and an entrance about 1,000 feet wide, with a rise of tide of only $6\frac{1}{2}$ feet at springs outside, Fig. 3. There are three inner channels, having depths of 10 feet for $3\frac{3}{4}$, $3\frac{1}{9}$, and $1\frac{2}{3}$ miles respectively, and an outer channel, $1\frac{1}{3}$ mile long, with depths of $16\frac{1}{2}$ to 39 feet, obstructed by a bar at its extremity having a depth of barely 8 feet over it at low tide. The bay of Arcachon on the French coast, and of San Martino on the coast of

Portugal, as well as the estuary of Mikindani on the east coast of Africa, furnish similar examples. The formation of these channels, above and below the neck, may be traced to the following causes. The increased speed of the current through a narrow neck, at the outlet of an estuary with a sandy bed, creates a deep hollow, leading into which the ebb, having drawn the sands from above which are unable to remain in the hollow, has gradually formed a channel in the estuary; and the flood-tide has similarly formed a channel below the neck. The sands thus carried along create banks inside and outside the estuary, which in estuaries devoid of rivers, tend to attain a state of equilibrium, undergoing very little change. The lengths of the deep channels, above and below the neck, are greater in proportion as the water flowing from each channel is larger in volume, and the neck deeper. Consequently, a vast estuary, especially if reinforced by the large tidal capacity of a river up which the tide flows for a long distance, augments the discharge above the neck during the ebb, and aids the deepening of the inner channels and the maintenance of the estuary. Below the neck, tides with a large range are especially favourable for forming the outer channel, and for maintaining a pass over the bar. The correctness of the foregoing explanation is rendered more probable by the consideration that the ebb and flood waters, on issuing from the neck, must rapidly lose their velocity in spreading over great widths, and therefore can then have only a feeble scouring action on the channels, which is confirmed by observation. Thus Mr. Guérard has stated that the depth of water over the bar at the mouth of the Rhone is to some extent independent of the discharge of the river.[1] Similarly, during the progress of the Seine training-works, it was found that the current issuing from the trained channel had little effect on the banks in front of the outlet. The velocity, also, of the flow over the bar of the Mersey is very small, and does not scour the sand of which the bar is formed; whereas the currents in the neck in front of Liverpool have an average velocity of 5 to 6 knots an hour during springs, so that the scour must be increased as the neck is approached. The inner and outer slopes of the bar, moreover, are steeper than those which a similar embankment would assume elsewhere; for, owing to the small quantity of alluvium brought down by the Mersey, the slopes of the bar and of the channel are those of cuttings excavated by the currents. The

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[1] "Amélioration de l'Embouchure du Rhône," A. Guérard, Congrès de Navigation intérieure. Paris, 1892, p. 34.

Author has also pointed out elsewhere [1] that, in the tidal Garonne, the hollows which are formed alongside a projection in the bank, causing a reduction in the width of the channel, are due to the ebb above the point, and to the flood below, otherwise the hollow which follows closely the curve of the projecting bank both above and below the point, would diverge from the bank on each side of the point if the scour was owing to the impulse given to the currents beyond the point by the narrowing of the river. It is therefore certain that contractions in tidal rivers produce their effects above, in relation to the direction of the current, rather than below, and that these effects depend on the rise of tide. It also follows that the effects of necks, as described above, should be visible along the whole course of tidal rivers, and in tideless rivers should be propagated above similarly to below, which observation appears to demonstrate. Beyond certain limits the influence of the neck upon banks in the sea necessarily ceases.

The coarser and heavier portions of the sand brought into the neck by the flood-tide stop in this channel, and are carried seawards again by the ebb; whilst the finer particles are carried on to the banks; and there the small waves put them again in suspension, so that they are drawn into the channel by the ebb currents, and return to the sea with the coarser sands during the ebb-tide. This explains how Arcachon bay, Poole harbour, and other estuaries are maintained, in spite of the abundance of sand which surrounds their entrances. The height of their banks depends upon the depth at which the little waves inside lift the sand, and on the currents which pass over the banks. The sands transported as above described settle outside the neck, on the sides of the outer channel. The channels branch out in estuaries devoid of rivers, generally extending close to their shores. In estuaries into which a river flows, an inner bar is sometimes found above the channels, as for instance in the Gironde and the Foyle, Figs. 13 and 15, Plate 4; but this bar does not appear to be due to any influence of the neck, which on the Gironde is $11\frac{3}{4}$ miles distant, and on the Foyle $11\frac{1}{8}$ miles. The inner bar is due to an enlargement in the channel; and it shows that the river should be trained down to a point where the channel due to the neck is sufficiently deep.

The banks seaward of the neck depend mainly on the conditions of the coast. The sand discharged from the estuary settles at the sides and end of the channel; and the portion

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[1] "Étude sur les Rivières à marée et les Estuaires," H. L. Partiot. Paris, 1892.

deposited on the side from which the materials travelling al the coast come, arrest these materials, and give rise to a bank. the sand transported to the extremity of the channel reach descending sea-slope, it forms a mound, unless removed b littoral current or waves. This mound, which diverts ur water the sand travelling along the coast, forms a bar, wl height depends on the action of the neck and the abundance of sands, and through which the flood and ebb waters for passage. If the materials from the estuary do not meet wi descending slope, and deposit at the limit of action of the n the channel soon elongates, and the bar progresses seaw Though a narrow outlet, accordingly, does not always remove bar at the mouth of estuaries, nevertheless, if the state of estu with a neck are compared with funnel-shaped estuaries in w the ebbing waters spread over a great width, leaving a sha channel intersected by shoals which are real bars, the Au considers that estuaries with necks will be unhesitatingly ferred. These necks bring all the water in the estuary into channel for deepening it; on the sea side they concentrate flood-tide waters so as to open a channel of access towards estuary; and the ebb-tide creates for its discharge a cha which extends sometimes beyond the limit of action of the r removes the bar further away, and lowers it. Some examples given in the following Table of the position and depths over bar in this class of estuary:—

Name of River or Estuary.	Distance of Neck from Bar.	Depth of Water over the Bar.	Remarks.
	Miles.	Feet.	
Jade	8¾	42	Plate 4, Fig. 2.
Gironde	15	29	Plate 4, Fig. 13.
Tagus	5½	36	Plate 4, Fig. 14.
Scheldt	10 14¼	25 25	The Scheldt flows througl channels into the North
Foyle	3½	48	Plate 4, Fig. 15.
Mersey	9⅓	9	Small estuary above neck tensive sandbanks b strong tides.
Rio Grande do Sul	2¾	12	Rise of tide, 2 feet.
Tay	8¾	21	Plate 4, Fig. 11.
Scorff and Blavet	1½	18	Small estuary.
Liffey	1⅛	15	Artificial estuary.

As the Foyle has a minimum depth of 48 feet in the main channel, and of 42 feet in the central channel between the neck and deep water in the sea, it may be said to have no bar. The shortest lengths and smallest depths are naturally found in the smaller estuaries. Since the estuaries protected by a neck have existed for centuries, it is evident that the sands brought in by the flood-tide are carried out again by the ebb.

Advantages of Estuaries with a Narrow Outlet.—As necks cause a channel to be formed seawards, any works narrowing the outlet of an estuary would produce a displacement seawards, or the lowering of any bar within the limits of action of the contraction. Consequently works of this kind would produce an effect at a considerable distance beyond the outlet, and might, therefore, be created on the foreshore more economically than those which would be required for training a channel into deep water, or for maintaining the depth over the bar by dredging, sometimes to an indefinite extent.

Reclamations in Estuaries.—Riparian proprietors, and persons who have carried out works for improving estuaries, have often caused accretions on the shores of estuaries, and reclaimed very valuable land. It has been stated that the deposits formed behind the training walls were eroded from the estuary, and thus compensated by an increase in depth elsewhere for the reduction in tidal area; but the motion of the sands above the necks of estuaries is at variance with this view. It is true that the alluvium accumulating behind the training-walls comes from the estuary; but the sands brought in by the flood-tide, which partially deposit outside the channels, will fill up the hollows thus formed at least to the level of the original deposits, owing to the causes which regulated their height, so that the reclaimed area will not be compensated for, and there will be a diminution in the volume of tidal water entering the estuary. Before attempting, therefore, such reclamations, the possibility of excluding a corresponding volume of water from the estuary, without injuriously affecting the maintenance of the channels both above and below the neck, or the action of the tides on the bar, should be investigated with the greatest care. It may occasionally be possible; but the Author considers that these reclamations are almost always injurious to navigation.

2. Estuaries into which Rivers Flow.

Those estuaries alone are included in this class into which large enough rivers flow to affect their condition, especially at

their outer end. They will also be divided into funnel-shape estuaries, and estuaries having a narrow outlet.

Funnel-Shaped Estuaries.

In order to explain the formation of funnel-shaped estuarie and the actions which take place in them, the Author will refer t the estuary of the Seine, which he has had occasion to study in very special manner.

Investigation of the Seine Estuary.—Previously to the improveme works commenced in 1844, the Seine estuary extended up to L Mailleraye, 40 miles above Havre, Fig. 4, Plate 4. As the rive above this point possessed depths of 23 to 50 feet at low water fo long distances, it constituted a great inner basin separated fro the sea by the sands of its estuary. On the Meules bank, abou 2 miles below La Mailleraye, the depth was only 7⅓ feet at lo water, below which a series of sills existed, over one of which, a Villequier, there was a depth of only 1⅓ foot at low water; whils below Quillebeuf there were shoals over which the depth was onl 6½ to 4 feet. The width of the river, which was 1,000 fee between Rouen and La Mailleraye, increased to 4,100 feet a Villequier, and 9,840 feet at Quillebeuf; and it reached 5 miles i front of Honfleur, and 6⅔ miles opposite Havre. The estuar altogether formed a long weir, which kept up the summer water level of La Mailleraye 16½ feet above low water of spring-tides a Havre.

Various circumstances indicate that the Seine in old time flowed through a deep bay into the sea. The tide indeed mus formerly have extended much further up the river than at present for the slope of the Seine at a low stage between Rouen an Bougival, near Paris, a distance of 102 miles, still averages onl 0·105 per 1,000, in spite of the raising which all this part of th valley must have undergone; and the quays of Rouen are at th same level as those of Havre. The stratum of rock, moreove which extends over the bottom of the bay near Tancarville, is abou 30 feet below low water at Havre. Lastly, the sands near Havr extend to more than 46 feet below the same level, outside the soli strata at the entrance to the bay, which in old times formed par of the adjacent coast. The old formation at the mouth of th Seine, underlying the alluvium, consists of the middle and uppe chalk on the east side, and of the lower and middle jurassic bed to the west, similar to the adjoining coasts.[1] The estuary face

[1] "L'Estuaire de la Seine," M. Lennier. Havre, 1881, vol. i. pp. 18, 19.

the prevailing westerly winds; and the tidal wave, coming in from the north-west, creates currents which bring into the bay the débris eroded from the coast between the cliffs of Calvados to the west, and Cape Antifer to the north of Havre. The chalk cliffs between this cape and Havre, being only 15 miles in length, supply merely a small quantity of shingle, sand, and silt; but the shingle has formed a beach up to the mouth of the River Lézarde near Harfleur, whose extremity forms Hoc Point. The jurassic coasts of Calvados, however, furnish an abundant supply of sand, which constitutes the main portion of the marine deposits which have been brought into the bay through the large entrance, 6½ miles in width.

Filling up of the Bay of the Seine.—The waters of the Seine, flowing in a channel 1,000 feet wide at La Mailleraye, were evidently incapable of counterbalancing the sea-water, and consequently the once deep bay filled up with sand. If the entrance had been only about 1¼ to 2 miles wide, the Seine might perhaps have remained deep, on account of its discharge and the efflux of tidal water on the ebb, instances of which are found elsewhere. Notwithstanding, however, the larger quantity of tidal water entering the bay, it has been filled up; and the Seine flows over the large weir of sand which the sea has formed. Observations in the bay of the Seine have proved that when a portion of the estuary has been withdrawn from the action of the river, by a change in the direction of the channel, it has soon been raised, the sand first deposited being brought from the part directly below. Similarly, when the construction of a training-wall formed a closed angle between the wall and the shore, the sand which filled up this angle came from just below, producing a hollow, which in its turn was filled up by the sand from below; and this action progressed seawards. When the hollow, temporarily formed, reached the end of the training-wall, the river water flowing into it caused the Seine to make a sharp turn at this point, which was gradually rectified by the filling up of the hollow with sand. The periodical changes, however, of the channel, which promoted the formation of banks in one part, made the river undermine accretions in another part during the ebb and carry the materials seawards, which served to keep down the average level of the bed of the estuary; and therefore the English were very wise in refusing to allow the Mersey to be trained through its upper estuary, which the changes in its channel have helped to preserve up to the present time.

A portion of the deposits which still take place is due to the meeting of the currents which flow into the Seine estuary, for all

causes which reduce the velocity of waters charged with alluvium give rise to accretions.

Flood-tide Pockets.—In some parts of the estuary of the Seine, blind channels closed at their upper end are formed by the flood-tide, termed flood pockets. The current of the early flood-tide is fairly rapid, and soon attains its maximum; and if at that time two currents converge to the same point, or if the flood-tide impinges upon a concave bend of a training wall, or of the shore, a powerful erosion occurs; but as the velocity of the flood soon diminishes rapidly, it does not generally form a long channel. Nevertheless, the flood-tide may deviate the main channel formed by the ebb, if in forming a pocket it meets the ebb-tide channel, and thereby provides a new exit for the ebb waters.

Nature of the Sands forming the Seine Estuary.—The deposits of sand found near the bed of the Seine between Paris and Rouen, prove that the river has carried some sand down; and its estuary must, therefore, contain a certain amount of sand from inland. Nevertheless, the volume must be small, since the basin of the Seine consists mainly of permeable strata; and having in old times been covered with forests, the river was noted for its purity; whilst in borings made at Aizier, marine sand alone was found. At the present day, Paris absorbs all the sand the river produces, so that the river now brings hardly anything into its estuary, beyond silt during floods.

Propagation of the Flood-Tide.—The introduction of sand by the flood-tide at the mouths of rivers has been attributed to the sea-water, owing to its density, flowing along the bottom like a wedge, and lifting the fresh water. Observations indicate that the sea-water ascends only a short distance above the mouth, and that the propagation of the tide is everywhere effected by driving back the river water. The flood-tide, at some distance from the mouth, has been proved by experience to drive back the descending waters more easily along the banks and bed of the channel where the current is less rapid; and nearer the sea, the action is analogous; and the flood-tide, entering along the bed and sides of the channels, carries along some of the sand, which partially justifies the wedge theory. The fine sand and silt, however, are carried in the mass of the current, and the fresh water mingles with the salt water, although the saltness of the water remains greater at the bottom in the centre of the channel than at the surface; but, owing to the mingling, the fresh water becomes more salt as it approaches the mouth, and it cannot be said that the sea-water penetrates under the fresh water and lifts it. There is, in every section, a successive

driving back of the layers of water, according to their velocity, even when the river only contains fresh water. In flood-time, this action is not powerful enough to reverse the more rapid portions of the downward current. Thus, in the roadstead of St. Nazaire, the current on the surface does not change its direction during the great floods of the Loire; but the flood-tide runs up underneath, and makes vessels of large draught swing round. Sometimes the whole river preserves its ebbing flow, its speed merely being reduced during the flood-tide. When the tides are very feeble, the fresh water spreads out on the surface for some distance over the sea, as happens at the mouth of the Rhone in flood-time.

Action of the Wind.—The wind had two principal effects in the estuary of the Seine up to the commencement of the training-works. During high tides, the westerly winds and the funnel shape of the bay facilitated the entry of the tidal waters, so that at Tancarville and Quillebeuf the level of high water was raised about 20 inches, which was subsequently lost in the trained channel. Another effect of the wind in the estuary was noted by Mr. Godot, who observed that so long as the channel was at a distance from the southern shore, being exposed to the prevalent winds, and especially those from the south and south-west, it was constantly driven against the northern shore. These kinds of effects should be investigated in each special case, but could not occur in a trained channel.

The tidal wave travelling from Cherbourg to Havre produces two secondary waves, one going from Cape Antifer to Havre, and the other from Port-en-Bessin to Honfleur. These two waves meet at the mouth of the Seine in somewhat contrary directions, and do not produce the raising of high-water level which is found in the Bristol Channel and the Severn.

Conditions necessary for the Preservation of an Estuary.—The description of the Seine estuary, and the explanations furnished seem to the Author to demonstrate that, in order to preserve an estuary, an equilibrium must exist between the action of the sea and of the flood-tide, and that of the fresh-water discharge and tidal water which flow away during the ebb. When an estuary has too large an entrance, or too expanded a form, it is inevitably filled by degrees with sand. This result also depends upon the contributions of the river and the sea; for a bay which opens upon a deep shore may be filled up by alluvium from a river, and a bay which receives no sediment from a river may be filled by sand from the sea. Lastly, the width at the entrance of an estuary may be such as to produce an equilibrium between the effects of the flood and ebb, which preserves the estuary, whether or not it

receives the alluvium of a river. The way, therefore, to improve a river flowing into a funnel-shaped estuary is to reduce the width of the river by training-walls, prolonged out to deep water in the sea. The estuary would be protected by narrowing the width of its entrance; and it would then be possible to reduce the length of the training-walls of the river, by connecting them with one of the channels which would be formed above the neck.

Improvement of the Mouth of a Tidal River.—As the volume of water discharged by a tidal river increases in proportion to its proximity to the sea, the width between training-walls must be enlarged towards the outlet. A method of calculating the increasing sections of the channel seawards [1] was employed for an investigation on the Loire in 1869, and was recently applied to the Weser by Mr. Franzius; and the Author has lately developed it.[2] The formula for determining the future discharge of a river about to be improved depends upon the new form which the tidal wave ascending the river will assume after the execution of the works; and the formulas hitherto obtained can only be used, with the data available beforehand, by neglecting certain terms. On the other hand, the average velocity of the current, which requires to be known at the outset for these calculations, can only be determined approximately by experimental formulas, or by comparison of the future state of the river with observed facts under analogous conditions. Nevertheless, the results obtained by these formulas accord sufficiently with observations to be accepted. As the discharge during the flood-tide is greater than during the ebb, it is expedient to employ it for calculating the sections of the channel, as these should be able to discharge the maximum quantity of water which they receive.

Dredging.—If the bed of a river is capable of being eroded, the currents scour the bottom during the construction of the training-walls, and after their completion; and the flood-tide carries back the eroded materials behind the training-walls. Thus, on the completion of the training-walls down to the River Rille in 186[illegible] the Seine had scoured its bed to an average depth of 14¾ feet between La Mailleraye and Tancarville; and the flood-tide had brought in behind the training-walls 22,368,000 cubic yards of silty sand. Silt, sand, or gravel pass down with the water in a river with a movable bed. If the velocity of the current in

[1] "Étude sur le mouvement des Marées dans la partie maritime des Fleuves," H. L. Partiot. Paris, 1861, p. 23.

[2] "Étude sur les Rivières à marée et les Estuaires," H. L. Partiot. Paris, 1892, p. 4.

creases, more material is carried along, and the bed is eroded; and, if the velocity diminishes, the bed is raised by the deposit of material. Consequently, if the channel of a river with a movable bed is deepened by dredging, without a corresponding reduction in width by training-walls or other means, the sands, if sufficiently abundant, will soon fill up the excavations, and destroy the effects of the dredging. These considerations explain the effect of training-walls which narrow the bed of a river, and the inconveniences of dredging under unfavourable conditions. If the amount of sand brought down by a river is small enough, it is possible to maintain the desired depth by constant dredging; but if the materials brought down are very abundant, they fill up these excavations again, rendering the dredging and expenses useless. This refilling renders sometimes the results attained by dredging uncertain, and may prove a danger to vessels. This method of obtaining the requisite depth has been widely adopted in recent times, owing to the reduction in cost of dredging operations; but it is an economical question, whether it is preferable to burden the future with works which must be continually renewed, or to undertake more costly works which avoid indefinite expenses. The choice depends on circumstances; but the Author considers that the second alternative should generally be adopted if the cost is not excessive, and that works requiring almost constant renewals, such as dredging in a movable bed, should be resorted to as little as possible.

Dredging enables depths to be obtained which scour could not effect; and a deeper access has been provided by this means to the port of Newcastle than could have been created by the discharge and tides of the Tyne. The formation, deepening, and maintenance of most ports and their entrances necessitate dredging, which may also be employed for facilitating the action of the currents on the bed of rivers and estuaries. Nevertheless, wherever natural causes tend to fill up the channel again, large dredging operations should not be undertaken, unless the interests involved amply justify the expenditure.

Successive Lowering of Movable Sills.—When a sill has been lowered by certain works, leading to a lowering of the low-water level at the same place, the slope of the ebb is increased above, and the sand formerly retained by the sill is carried down towards the sea. The next shoal above is lowered in its turn by the increased slope and velocity of the ebb, which produces a corresponding scour higher up; so that the removal of one shoal may lead to the lowering of shoals for a long distance above. The improvement of

the Seine below Villequier, and the dredging of the Meules bank below La Mailleraye have produced a lowering of the bed of the Seine for about 19 miles above this latter point. On the Gironde, the dredging of the natural sill, Beychevelle, near Pauillac, over which there was a depth of 9½ feet at low water, has brought down the sands from above, has made other sills disappear, and has improved the Garonne as far up as Bordeaux. This connection between different parts of a river shows how important is an investigation of the shoals of a river, for a simple work on one may lead to a spontaneous partial, or total improvement of a more troublesome shoal higher up.

When the size of the channel has been suitably determined, and a sufficient velocity obtained to ensure the scour of the bed of a river, an equilibrium will be established between the discharges and the depths. If a hard shoal is able to withstand the scour of the current, it is certain that on the removal of the shoal to the desired depth by dredging or other means, the channel will be maintained for the future by the current.

Form to be chosen for the calculated Section of a Tidal River.—The proper sectional area of the channel having been calculated, its form has to be determined, the simplest being a trapezium. The calculated depth, being the mean depth in the section, is necessarily less than the maximum depth which will be obtained in the curves, and wherever the river has a well-defined, deepest channel. Where the main current crosses over to the opposite bank, the bottom is uniform; and as the current is oblique to the general direction of the river, the depth at this part is rather less than that given by the formulas, which has rightly led Mr. Fargue and other engineers to point to the necessity of reducing the width a little at these places. The Author would propose to adopt a width equal to the average width multiplied by the cosine of the angle which the central line of the river makes with the approximate line of the main channel. The crossing over of the current, and the depth of the channel along the concave banks have also led to the proposal to construct the training-walls alternately along each bank, so as only to maintain the direction of the channel along the concave portions. The variations, however, of the line of deepest channel, produced by variations in the discharge resulting from floods and the tides, are such as to prevent the securing of a fixed channel, except by two nearly parallel longitudinal training-walls.

It has also been proposed to form the cross-section of tidal rivers with a low-water and a high-water channel, the former corre-

sponding to the discharge of a river at low tide and at a low stage, bounded by nearly low-water training-walls, and the latter a much wider channel, affording a free passage for floods and the tidal waters. This system has the advantage of concentrating the ebb in a small trained channel, of providing the space required for floods, and of admitting a much larger quantity of tidal water, which partially returns down the low-water channel and deepens it. There is, however, reason to fear that the spaces left behind the low training-walls, and which bound the high-water channel, might be silted up by the tides higher than low-water level, and might end by being covered with vegetation and forming part of the banks. This system has been adopted on the Weser; and in reply to this objection of the Author's, Mr. Franzius, the engineer of the Weser, stated that the spaces left behind the low training-walls, and which still comprise a void of about 25,000,000 cubic yards below low water, would be filled by alluvium scoured from the low-water channel, and would thus contribute to its improvement. It would only be after the filling up of these large spaces that the accretions could reduce the sections proposed for the high-water channel; and in this interval a state of equilibrium will be established in the river, which will by degrees render the assistance of the large masses of water spread over these lateral spaces less and less necessary; whereas for a very long period the action of these masses of water will have been very useful in regulating the river; and as the arrangement involves no serious expenditure, Mr. Franzius considers that it would have been a mistake not to have profited by it. These views appear to the Author to be sound; but, nevertheless, it must be noted that the eventual widths will be those between the low-water training-walls, and, therefore, should be calculated according to the suitable cross-sections, omitting the side spaces of the high-water channels, for these will only serve for a time as a means of construction, and to bring the river into the desired condition.

Closure of Secondary Channels.—If the channel divides into several branches, their total sectional area must be rather larger than that calculated for a single channel, owing to the increased friction. The quantity of tidal water coming in is consequently rather greater—an advantage which must be considered. Secondary channels, however, have almost always the inconvenience of creating shoals, which can only be removed by uniting all the waters of the river in a single bed. To solve this difficulty on the Weser, Mr. Franzius has closed some secondary channels by a low dam midway, and by the longitudinal training-walls of the

principal channel at their extremities, kept down to low-water level so that the flood-tide can still ascend them. The action of the tide has been increased in the main channel, which has deepened rapidly; and the materials scoured out have been carried by the currents over the dams at the entrance and outlet of the secondary channels, in which they have been partially deposited. The damming of these branches produced a temporary raising of the low-water line, since the river below the point where the secondary channel branches off no longer afforded an adequate section for the discharge of the ebb. This raising, however, has nearly disappeared in consequence of the deeping of the main channel; and it is certain, that owing to the general improvement of the river, the level of low water will soon fall lower than it was previously to the works. The accretions resulting from the damming of the branches by the low training-walls will before long rise above low water, and become covered with vegetation, unless some stream can be led into them; the tides will eventually cease to flow through them; and the water which they received will be lost for the maintenance of the river. As, however, the depth of the main channel is the object in view, and the branches disturb the bed of the river, and produce a loss of energy in the tidal wave, the Author is of opinion that secondary channels should be suppressed as far as possible, and that the main channel should be widened so as not to possess a greater depth than necessary for the navigation.

Form of the Trained Channel in Plan.—The quantity of tidal water entering a river is proportionate to the size of the surface of the river, and it is therefore advantageous to increase it. As the sectional area of a river should continually increase towards its mouth, whereas there is no advantage in increasing the depth beyond the requirements of navigation, it has been concluded that a tidal river should have a regularly enlarging channel down to the sea. This form is certainly the most favourable for the admission of the flood-tide, and for raising the high-water line inland; but it is not so as regards the effect of the ebb for maintaining the channels, and especially for freeing the entrance from the sands which tend to block it up, because the water is dispersed over an excessive width. The trained channel must, therefore, be extended beyond these sands to the deep sea. The form of the channel, moreover, should offer the least possible obstacles to the propagation of the tidal wave; and since curves are unfavourable to this propagation, the channel between the two training-walls should be straight, which form is also suitable for the variations

which the serpentine form of the deepest channel may undergo between the training-walls, from the effects of the tides and floods. If the prevalent winds and the direction of the tidal wave come towards the shore, and if travelling sands and banks are found at the mouth of the river, the most economical solution would appear to be to train the channel at right angles to the coast. The prolongation of the jetties in a straight line to deep water would produce an advance of the foreshore, which would soon obstruct the entrance, and necessitate a further prolongation seawards; but Mr. Bouquet de la Grye has indicated a method of avoiding the difficulty in the case of the River Senegal.[1]

Arrangements to be adopted at Outlet.—Near low-water mark, a curved jetty on the side of the channel opposite to the quarter from whence the sands come, would stretch into the bed of the river, so as to receive the ebb on its concave face, Fig. 5, Plate 4. A passage would be left facing the jetty for a portion of the sand travelling along the coast; and this sand would push the ebbing tide against the jetty. This jetty would direct the current against the concave face of another curved jetty on the opposite side of the outlet, which would convey it to deep water, with the alluvium brought down by the river. The portion of the travelling sands coming against the convex side of the second jetty would pass round its outer end, and would be carried by the current of the river approximately in its previous direction; and the winds and waves would soon throw it back on the coast. It is assumed in this arrangement that the waves can act on the sands at the end of the jetty, and over the whole width of the outlet. The vertical limit of the effective wave-action being somewhat restricted, the depth at the outlet is also limited, unless it is influenced by a littoral current as well. The travel of the sands along the coast, however, is not arrested, so that they are unable to cause an indefinite advance of the foreshore.

As the double inflexion of the current in front of the entrance to the trained channel might check the influx of the flood-tide, and as a deep channel is better maintained along a curve than in a straight bed, it might be well to train the channel in one or several circular arcs of very large radius, with the extremities of the training-walls projecting into deep water at an angle to the coast, so as to facilitate the passage of the sands scoured from the outlets by the ebb- and flood-tide currents, Fig. 6.

In neither case are the parts of the estuary outside the training-

[1] "Revue Maritime et Coloniale," June, 1886, p. 543.

walls protected against the action of the flood-tide; and being deprived of the changes of the channel, and offering a wide entrance to the sea, they are exposed to rapid silting up. As a very great portion of the water, moreover, which covers them returns to the sea over the banks without assisting in the deepening of the channel, the partial reclamation of these littoral spaces would be effected without detriment to the navigation.

Since the formation of sand, and its travel along the coast are the result of permanent causes, the sand must either be allowed to travel along so as to cause as little inconvenience as practicable to navigation, or it must be stopped and utilized. The first system has been just described; but it might not always secure an adequate depth. The sand might be arrested by constructing, at right angles to the shore-line $a\,b$, a groyne $c\,d$, which might have to be prolonged to d', at an angle to its first direction, to prevent the sand travelling round the end of the groyne, Fig. 7, Plate 4. The sand will accumulate in the angle $a\,c\,d$ formed by the groyne, and rising up the gentle slope of the groyne, will form dunes which can be stopped from travelling inland by the processes previously described; whilst the accumulation can be prolonged along the shore by successive groynes $d_1\,d_2\,d_3$, and thus wooded lands could be formed along the coast. The new outlet would be trained to the desired depth in the sea, sheltered from the accumulation of sand thus formed, and directed so as to scour away any sand coming either from the sea or from inland. If an estuary, A B C, had to be crossed, the prolongation of the shore-line $a'b$ might be hastened by a supporting groyne suitably directed. Nature exhibits examples of outlets formed in an analogous manner, the river being impeded by a bank of sand projecting from the side from which the sand travels; but as this bank is mostly under water, and nothing is done to raise it, the sand eventually travels round it. It would only be necessary to complete the work already begun naturally, by aiding the raising of the bank; and the improvement of the channel could easily be effected behind the reclaimed lands. At the mouth of the Foyle, the foreshore has progressed across the bay, forming a narrow outlet for the river, and a long sandy beach bordering the sea; dunes have also been formed; and the sandbank of Tuns, on the right side of the channel, is continually growing by the accumulation of sand brought along the coast.

Small-Scale Models, and Wattling.—In recent investigations of estuaries, small-scale models have been sometimes employed of the estuary to be improved, in which the vertical scale is necessarily

much larger than the horizontal. The movable banks are represented by very fine sand, as they exist previously to the works; the training-works and jetties proposed to be constructed are formed of little strips of metal; and the tidal waves are produced by an immersed float, or by a movable reservoir set in motion by clockwork; whilst a reservoir with a sluice supplies the discharge from inland. The currents produced in these models displace the sand, which is deposited according to the conditions of the site and the works introduced. The banks at the mouths of certain tidal rivers have been fairly reproduced, as, for instance, those of the Mersey. In these models, however, the shore and the banks are distorted, owing to the difference in the scales; and account is not taken of floods, waves, or the action of wind, so that their results must be accepted merely as indications without much claim to exactness.

On the tidal Garonne and the upper Gironde, a surer method was adopted, too costly to be used for the extensive and numerous experiments that can be made with small models, but affording much better results, which may often lead to important economies in the execution of the actual works. The system consists in placing wattlings along the line of the proposed works, fastened to a double row of piles driven at intervals apart by aid of a water-jet, which also enables the piles to be readily shifted if necessary. When, however, the line adopted proves satisfactory, these wattlings serve for a long time in place of training-walls, and accretions take place behind them; and when more solid works become necessary, they often provide a support, and enable the amount of rubble for the training-walls to be considerably reduced, affording a saving much in excess of their cost. The wattlings on the Gironde, raised only 3¼ feet above low water, cost 14*s.* 6*d.* per lineal yard; and each square yard extra cost 3*s.* 1½*d.* This system would be applicable to a number of cases.

Estuaries with Narrow Outlets.

Utilization of all the Water of an Estuary.—Though the spaces at the back of the training-walls in a funnel-shaped estuary might be reclaimed in most cases without injury to the river, the Author considers that it would be better to utilize all the tidal water flowing over the estuary for the improvement of the channel and lowering the bar, which may be accomplished by constructing high jetties between the channel and the shore on each side, Figs. 8 and 9, Plate 4, making all the water in the estuary pass

through the outlet-channel. This conversion of a funnel-shaped estuary into an estuary with a narrow outlet, will produce the ordinary effects, of a great depth in the neck, one or more channels in the estuary, one of which will form a continuation of the river-bed, and an outer channel extending across the bar, if the bar is situated within the zone of influence of the neck. It would even be possible to reduce the length of the training-walls in the estuary, because one of the channels formed would be in continuation of the trained channel. According to circumstances, either a straight channel might be formed, as in the case of the Liffey and the Tyne, or a channel with curves of large radius as on the Tees; and if a curved channel was selected, it would be advantageous to continue a low training-wall along the concave bank as far as the neck, Fig. 9, Plate 4.

Training-Walls with varying Curvature.—In cases where the scour of the ebb predominates for deepening the channel, it must be remembered that the current following along a concave training-wall loses a portion of its energy by friction against the wall, in proportion to the length of the wall. As, however, the centrifugal force is in inverse ratio to the radius of curvature, the friction might be partly compensated for by diminishing the radius, in proportion as the training-wall extends seawards. The training-walls at the mouth of the Dwina in the Baltic appear to have been designed with this view.

Reservoirs.—The discharge of an estuary during the ebb depends upon the volume of tidal water which enters, the amount which is forced back by the flood-tide, and the relative discharge of fresh water in flood-time and during the low stage. Reservoirs within the neck, and even a certain distance up a river, may very usefully increase the volume of the ebb, when in good condition; and a tidal river, besides discharging its fresh water, affords a passage at the same time to a large volume of water which it has stored up like a reservoir. Thus, for instance, though the quantity of water backed up by the flood-tide in the Garonne, the Dordogne, and the Isle, has only a small influence on the discharge of the ebb at the outlet of the Gironde, 47 miles below the confluence of its two main tributaries, the action of the reservoirs formed by the Garonne and Dordogne increases rapidly on approaching their confluence into the Gironde,[1] Fig. 13, Plate 4. Moreover, as the discharge at each point regulates the section, and consequently the

[1] "Étude sur les Rivières à Marée et les Estuaires," H. L. Partiot. Paris, 1892, p. 58.

volume of water which flows up and down at this place, the section, even of the outlet of the Gironde, depends upon the volume of water stored in the upper reservoirs formed by the two large rivers.

A similar effect is produced when a river traverses large areas covered and uncovered by each tide, for the outflow from these reservoirs increases the section of the channel below them, and usually increases its depth. The little river Odet, discharging only 140 to 280 cubic feet per second at its low stage, flows through a large mere 2 miles below Quimper, called Lédanou, which is in communication with several lateral branches maintained by small streams, together forming regular inner estuaries.[1] The rise of equinoctial spring-tides is $14\frac{3}{4}$ feet, and the capacity of these reservoirs amounts to about 18,000,000 cubic yards. The bed of the Odet below the mere constitutes a neck 8 miles long, 820 feet wide in its upper portion, and 720 feet wide at its outlet. The river, which is barely 12 miles long, and brings down very little alluvium, has a very small depth above the mere, and its high- and low-water lines have sharp slopes; but below the mere, the depth in the main channel varies from 17 to 40 feet, and even 50 feet, and the lines of high and low water are nearly horizontal. If a portion of this reservoir was cut off, the tidal water entering and leaving the river would be diminished; and though the tidal range might be slightly increased in the upper part of the river, the depth in the neck would be reduced; whereas an enlargement of the reservoir would produce a deepening in the channel below.

The Yare furnishes a similar instance, for near Yarmouth it flows through a vast expanse, called Breydon Water, which is uncovered at low tide; but as the range of springs on that part of the coast is only 6 feet, the river, along the 2 miles between the port of Yarmouth and the North Sea, only attains a depth of 10 to 14 feet.

The tidal water which enters a tidal river is generally much larger in volume than the fresh water; and it especially assists the ebb current in deepening the approach to the river, if, spreading over an estuary, it is concentrated into the outlet channel by a narrow mouth. Thus if the channel of the tidal Seine was prolonged to Havre between two training-walls, Fig. 4, Plate 4, so as to attain a depth of about 45 feet at low water, the channel would receive, during the flood of a spring-tide, about 3,000,000

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[1] "Procès-Verbaux des Séances des Sections," Congrès de Navigation intérieure, Paris, 1892, p. 645.

cubic yards of fresh water from inland, and 504,000,000 cubic yards of water from the sea. Including, however, the contents of the estuary outside the channel, between its shores and the proposed Villerville breakwater, the tidal water would be increased by 783,000,000 cubic yards; so that during the ebb, adding the fresh-water discharge during a whole tide, the total discharge of the Seine would amount to 1,293,000,000 cubic yards, as compared with 3,000,000 cubic yards of fresh water discharged during the ebb.

The reclamation of natural tidal reservoirs injured the port of Ostend, and sluicing-basins have had to be formed to supply their place. Estuaries with a narrow outlet are likewise reservoirs; and it is almost always very important to avoid reducing them by reclamations. This was fully appreciated by the Dublin authorities, who prohibited any reclamation of land within the artificial estuary of the Liffey, formed by breakwaters at its mouth. In order that reservoirs may be really useful, the waters which flow into them must not fill them up with sediment; their entrance must not be so situated as to produce dangerous eddies in the main channel; and the channel of the river below must be sufficiently wide or deep to afford a free outflow for the water from the reservoir and from the river. If the outlet is not large enough, the level of low water is raised; the river above is deprived of a portion of the tidal water; and the level of high water is depressed.

Changeable Narrow Outlets.—Some narrow outlets, like the outlet of Arcachon Bay, Fig. 1, Plate 4, are formed by the travel of sand or shingle along the coast; and their width is altered by the prolongation of the shore-line of drift, or by the erosion of the coast. If the shore-line is cut in various places, as at the mouth of the River Senegal, Fig. 10, Plate 4, the outlet is too changeable to produce the effect of a neck seawards; but this is not so above, although the changes in the outlet are not without influence if the neck is prolonged inland by a narrow stable channel. Thus the estuary channel has a depth of 59 feet opposite Arcachon; and the Senegal has a depth of 26 to 36 feet between its outlet and St. Louis. As the outlet-channel of the Senegal, diverted by the drift along the coast, is stopped at the Mousseguiob dunes, where the tenacity of the soil prevents erosion from prolonging the channel southwards, Mr. Bouquet de la Grye has proposed to create similarly a fixed outlet to the north, by guiding it between jetties arranged as shown on Fig. 5, Plate 4, so as not to stop the travel of sand along the coast. The Author has proposed the

adoption of a similar plan for creating a fixed deep entrance to Arcachon Bay, near the lighthouse of Cape Féret; and the changes of the outlet of the Yare were stopped by a similar expedient.

Investigation of various Mouths of Rivers.—The Author proposes now to examine some estuaries belonging to the second class, and to point out the theoretical consequences which appear to result from these investigations. In order, however, to understand better the phenomena taking place in these estuaries, it will be useful to note the facts observed at the mouth of the Rhone, where the range of tides is extremely small. As described by Mr. Guérard,[1] there is, at the mouth of the Rhone, a mound of deposit over which the river flows between two submarine banks; and the materials carried down by the river are deposited on the sides and end of the basin formed by the river, and raise them gradually, till at length, when the outlet becomes insufficient for the waters of the Rhone, a passage is forced through the bar at the end, which consequently varies in height.

The east coast of Great Britain is sheltered from the direct action of the prevalent westerly and north-westerly winds; and it is, moreover, intersected by great recesses, such as the Moray Firth, the Firth of Forth, and the Thames, reducing the quantity of sand and shingle travelling along the coast. The amount of drift, therefore, which reaches the mouths of the rivers, is sometimes very small, whilst it is greater in the indentations of the coast.

The Tay.—The River Tay, unlike the Seine, brings down large quantities of sand and detritus; whilst little material arrives from along the coast, Fig. 11, Plate 4; and Mr. D. Cunningham, M. Inst. C.E., has stated that the sands in the lower part of this river are continually descending to the sea,[2] their rate of travel increasing as they approach the contraction in the estuary at Tayport, a little below Dundee, where the width, which is about $2\frac{1}{2}$ miles above, is reduced to 270 yards, with a depth of 59 feet. The rise of the tide at springs at the mouth of the Tay is $15\frac{3}{4}$ feet. Two channels extend above the neck with depths of 18 feet, one to the north for 6,200 yards, nearly up to Dundee, and the other to the south for about 5,700 yards. Below Tayport, the sands and shingle have formed two converging banks, between which the river flows, with a bar at their outer ends, $8\frac{2}{3}$ miles beyond the neck, over

[1] "Amélioration de l'Embouchure du Rhône," A. Guérard, Congrès de Navigation intérieure, Paris, 1892, p. 22.

[2] Minutes of Proceedings Inst. C.E., vol. c. p. 182.

which there is a depth of 21 feet at low water. In this enclosure, the current increases in velocity out to the bar; and the sand is carried rapidly to the sea, partly in suspension, but mostly rolled along near the bottom. The left bank has formed a groyne, which retains the small amount of sand coming from the north, creating a little bank near Buddon Ness.

The travel of the sands is in exactly opposite directions in the estuaries of the Seine and the Tay, owing to their different origin; for the Seine estuary has been blocked up by sand coming from the sea; whereas in the Tay estuary, where the low-water level of spring-tides at Dundee differs by only 6 inches from low-water level in the sea, the tidal currents have brought down large quantities of sand into the lower estuary, which have increased the banks near the mouth without encumbering the channel.

Estuaries will next be considered which receive sand both from above and below, such as the Maas, the Gironde, and some others.

The Maas.—After receiving the waters of the Waal and the Leck, the Maas flows into the North Sea through several branches, the principal one of which passes Rotterdam; and the rise of average spring-tides is only 5 feet 7 inches. Receiving both the alluvium of the Maas and the sands of the Dutch coast from the north, the funnel-shaped estuary, Fig. 12, Plate 4, tended to fill up; and the action of the sea has been aided by reclamations alongside the river, its water area having been reduced from 42 square miles in 1739 to 27 square miles in 1860. The Rotterdam channel discharged through two branches into the midst of the banks which bordered the coast, it became shallower, and the bar was raised 4½ feet.

To remedy this condition, the Hook of Holland was cut through, and the Maas was regulated from Krimpen and Rotterdam down to the sea. The width between the jetties at the outlet, which was at first made 2,953 feet, has been reduced to 2,300 feet; and small groynes have been placed along the coast to the north, to check the progress of the sands. The lines of soundings of 33 feet, about 1½ mile off the coast, have not advanced seawards; but the smaller depths have notably decreased near the new outlet;[1] thus the head of the north jetty, built in a depth of 26½ feet at low water, is now in a depth of only 16½ feet; and the line of soundings of 16½ feet, which was formerly 1,100 yards from the shore, has gone 820 yards further out. Since 1880,

[1] "Le nouveau Chenal d'accès de la Mer à Rotterdam," Baron Quinette de Rochemont, Congrès des Travaux Maritimes, Paris, 1889.

however, this progression has ceased;[1] the deepening near the shore is proceeding slowly under the action of the concentrated current in front of the ends of the jetties; and, unlike all the other outlets to the sea in Holland, there is no sign of a bar or shoal opposite the new outlet. In spite of the present relatively stable condition at the outlet, it is to be apprehended that the sands from the north, which created the Hook of Holland, will eventually form a bank on the north side of the channel, and even overlap it; but an adequate depth might remain over the bar.

Hitherto the results of the work have been most satisfactory, for the minimum depth in a channel 110 yards wide, between the jetties and beyond, has reached $23\frac{2}{3}$ feet; and deep water has penetrated further into the channel. Except at Zuiden, about $3\frac{3}{4}$ miles below Maassluis, there was in 1891, over all the shoals between Rotterdam and the sea, a minimum depth of $21\frac{1}{3}$ feet at low water for a width of at least 110 yards.

The Gironde.—This estuary has been described at length elsewhere by the Author.[2] The rise of tide at the mouth of the Gironde is $16\frac{3}{4}$ feet at springs. A considerable amount of alluvium is brought down by the Garonne and the Dordogne; and sand is brought into the Gironde from the sea by the flood-tide round the Pointe de Grave, Fig. 13, Plate 4. Nevertheless, this long estuary maintains itself by discharging into the sea the materials brought into it. The contraction at the Pointe de Grave, which reduces its width from $6\frac{2}{3}$ to 3 miles, gives rise above to three channels, with depths of at least 33 feet for $9\frac{1}{3}$ to 10 miles from the Pointe de Grave. At their upper end in front of By, nearly 12 miles above Grave, there is a wide flat shoal or inner bar, over which there is a depth of 10 to $14\frac{3}{4}$ feet at low tide, which the Author considers to be beyond the influence of the neck, and attributes to the undue width of the estuary in relation to its discharge at this part. In the neck itself, the depth attains 100 feet; and a channel below, 15 miles long, extends to the bar, over which there is a depth of $29\frac{1}{2}$ feet. Beyond the neck, sand comes in abundantly from the west and south-west; and the channel leaves on this side a series of banks, through which it occasionally opens a passage. The materials brought down by the Garonne and the Dordogne are readily distinguished, and are found partly on these banks, and partly beyond the bar, $17\frac{1}{2}$ miles

[1] "Amélioration de la Voie fluviale de Rotterdam à la Mer," J. W. Welcker, Congrès de Navigation intérieure, Paris, 1892.

[2] "Étude sur les Rivières à Marée et les Estuaires," H. L. Partiot. Paris, 1892, p. 51.

from the Pointe de Grave. Although the width varies in the Gironde, the sectional area below mean tide increases regularly from the Bec d'Ambès to the Pointe de Grave, and even in the neck. The effect of the neck is most distinct; and the desired equilibrium for maintaining an estuary appears to be realized on the Gironde.

The Tagus.—A similar equilibrium is not attained in the Tagus, where a neck, about $6\frac{1}{5}$ miles long, separates its estuary from the sea, Fig. 14, Plate 4. The tide rises 12 feet at springs outside this neck, whose width is about $1\frac{1}{8}$ mile opposite Belem Castle, and is fairly uniform, and whose depth attains 118 to 160 feet. The estuary, known as the Bay of Lisbon, has a width of $5\frac{1}{2}$ miles; and there is a channel in it which has a depth of 33 feet as far as $4\frac{1}{3}$ miles from the neck; whilst the channel below the neck extends for $7\frac{1}{2}$ miles out to the southern bar, over which there is still a depth of 36 feet. The lower part of this outer channel resembles in form the Rhone bar previously described; it arrests the sands travelling northwards along this coast, and has formed the bank of Alpeidao, which resembles the banks outside Poole harbour and the estuaries of the Tay and the Foyle, due to similar causes. The Tagus is torrential throughout its course, passing abruptly from an insignificant flow to a very large discharge; it has a rapid fall down to its outlet into its estuary, and it carries along a quantity of sand and gravel. Consequently, this estuary tends to silt up, though it has existed for many centuries.

The Foyle.—This river flows into an estuary on the north coast of Ireland, $15\frac{1}{2}$ miles long and $13\frac{2}{3}$ miles wide, which is protected from westerly and north-westerly winds by the mountains of Donegal, Fig. 15, Plate 4. The sands are driven along the coast by easterly winds, as proved by the neighbouring outlet of the little river Bann; and these sands have formed a shore-line like that at Arcachon, which would skirt the east coast of the bay if a gap in the range of mountains near Londonderry did not give vent to the south-west winds. These winds turn the sands from the coast towards the north; and their action, combined with that of the east-north-east winds and of the littoral current, has gradually formed a triangular point, which has now a base of 6 miles and a projection of 4 miles, and has formed a neck between its extremity at Macgilligan Point and the opposite shore. Dunes have been formed by north-north-east winds on the northern shore of this triangle, and by south-west winds on the shore inside the bay. The neck, which is maintained by the outflowing waters, is about

1,470 yards wide, and has a depth of 72 feet. Above the neck, a channel, having a depth of 33 feet for 6 miles, has a bar 11 miles from the neck, over which there is a depth of $10\frac{1}{3}$ feet at low tide; and below the neck, a channel of similar width possesses a depth of 39 feet out to deep water. The sands arrested on the eastern side of the channel below Macgilligan Point have formed Tuns bank, which is very similar in shape to the bank outside Poole harbour, Fig. 3, Plate 4.

The Slaney.—Wexford harbour, on the east coast of Ireland, into which the little river Slaney flows, has a length and width of $3\frac{3}{4}$ miles, and is enclosed on the sea side by a long narrow spit ending at Rosslare Point, leaving on its north side an outlet 980 yards wide, with depths of 33 to 49 feet, Fig. 16, Plate 4. The rise of spring-tides at that part of the coast is only 5 feet. Two channels branch off above the neck, one of which, the Coal Channel, has depths of 10 to 26 feet for nearly 3 miles; and the other, leading to the port of Wexford, has depths of $6\frac{1}{2}$ to 10 feet, and at $2\frac{2}{3}$ miles from the neck has an inner bar over which the depth is only $5\frac{1}{2}$ feet at low tide. Seawards of Rosslare Point, a channel extends for $1\frac{1}{4}$ mile out to the outer bar, with a depth of 10 feet over it. The Dogger bank has been formed on the south side of the channel by the sand coming from the south, in the same manner as the banks at the mouth of the Tagus, Poole harbour, and other places previously mentioned. The small depth of the channels is due to the feeble rise of tide, the small discharge of the river, and reclamations in the estuary.

The Tees.—A fairly large quantity of alluvium is brought down by the Tees in flood-time; and its estuary also receives the sands which travel from north to south along the east coast of England. The Tees estuary is $3\frac{3}{4}$ miles long and $4\frac{1}{3}$ miles wide; and the sandbank which enclosed it to the east in advance of Tod Point, left it an outlet to the sea $1\frac{3}{4}$ mile wide, which has been partially closed by a long breakwater.[1] The rise of spring-tides at its mouth is 15 feet. Two channels have been formed above the outlet, one extending to the inner part of the estuary, into which the Tees flows at Cargo Fleet, and the other running westwards towards Greatham Creek. The improvement works carried out on the Tees, and their results have been already described in detail by the late Mr. John Fowler, M. Inst. C.E.[2] It has been possible to reclaim 2,600 acres from the estuary without injury

[1] Minutes of Proceedings Inst. C.E., vol. xc. Plate 8.

[2] *Ibid*, vol. lxxv. p. 239; also vol. xc. p. 344.

to the navigation. Latterly the accretions in the estuary behi the outer part of the half-tide training-wall on the left bank ha led to the removal of its outer end; and the prolongation of t north breakwater has been provisionally stopped. The widt left at the outlet has been reduced by a bank which has formed o the right bank near the end of the south breakwater. Th channel at this part has hitherto maintained the same depth; b time only will show whether the opening left to the sands of th coast is not wide enough to promote the silting up of the estuar In this case the north breakwater would be extended towards th end of the south breakwater, which would divert into the chann the water which escapes along the coast during the ebb, and b forming a fixed neck would ensure the maintenance of the desir depths in the neighbouring parts of the channels. A project for funnel-shaped mouth was rejected in 1842.

The Tyne.—In addition to training-works and dredging in t river up to Newcastle, the channel across the sandy bar, form by the sea at the mouth of the Tyne, has been protected by tw converging breakwaters, which enclose a little estuary 1½ mile lon and ⅔ mile wide.[1] These breakwaters extend into a depth of feet, and leave an outlet of about 1,000 feet between the extremities, the rise of tide at springs being 14½ feet. Th channel of the Tyne at the port of Shields has the same wid as the outlet, and depths of 26 to 36 feet at low tide.

The Liffey.—Two converging breakwaters have also been co structed at the mouth of the Liffey, at the approach to the port Dublin, enclosing an estuary about 3 miles long and 1⅕ mi wide, and leaving an outlet 1,000 feet wide, with a depth of feet at low tide, the rise of tide at springs being 13 feet.[2] The is a channel up to Dublin, improved by dredging, with a minimu depth of 12 feet; and an outer channel extends nearly a m beyond the outlet, with a depth of 18 feet; whilst the depth ov the bar, which formerly was only 6½ feet, is now 15 feet. project for a funnel-shaped mouth was urged for a long time the Liffey, and was finally rejected.

The Author would observe that there is hardly a case in Engla of the mouth of a river trained in a funnel shape to deep wat whereas closed estuaries with a narrow outlet have been crea in front of the Liffey, the Tyne, and the Tees. This latter syst

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[1] Minutes of Proceedings Inst. C.E., vol. lxx. Plate 3, Fig. 9; also lxxxvii. p. 148, and Plate 8.

[2] *Ibid*, vol. lviii. Plate 1.

appears to have been preferred by engineers, and the choice appears to the Author to have been amply justified by its success.

Final Considerations.

The divergence of opinion manifested by engineers as to the form to be given to the mouths of rivers is partly due, the Author considers, to its not having been sufficiently observed that the free propagation of the tides up a river, and their ready outflow, require the progressive increase of the sectional area of the channel far more than that of the width. A deep, narrow channel affords a greater discharge, and renders easier the propagation of the tidal wave than a shallow channel of the same sectional area. It is no doubt advantageous to augment to the utmost the volume of tidal water entering a river; but local contractions offer no serious obstacle to this, unless the sectional area does not comply with the law of the regular increase of the discharge, and of the propagation of the tidal wave up the centre of the river. The increase in the quantity of tidal water introduced may result from the creation of a channel increasing regularly in width seawards, with only the depth absolutely necessary for navigation. It may also result, as on the Odet and the Yare, from the existence or formation of reservoirs in places on the tidal river, or near its mouth. The concentration of the whole of the waters of an estuary in the channel during the ebb, by the creation of a neck near the sea, transforms the estuary into a vast reservoir at a favourable point, and assists very effectually in securing the same object.

The form of the channel through the estuary, and wherever it has to be regulated, should be arranged so as to preserve to the utmost the energy of the flood-tide in ascending the river, and also to facilitate the efflux of the ebb. It is expedient to adopt curves of very large radius, and to approximate, especially in the estuary, to a straight course.

The necks which certain estuaries form possess some precious qualities. Not only do they collect the waters for maintaining the channel during the ebb, but they also produce channels above and below, whose depth and length depend on the fresh-water discharge of the river and the tidal range. The upper channel formed by the neck enables the length of the training-walls through the estuary to be reduced, or only low training-walls to be adopted below a certain point. In all cases the training-walls must extend beyond the point where the river might form an inner bar, which is above the end of the channels due to the con-

tracted outlet, and almost always a long distance from the outlet. The channel below the neck nearly always extends far enough out to lower the bar. The influence of the neck extends a long way seawards of its jetties, and thus enables them to be constructed near the shore, and consequently more easily. The enclosure of the estuary, moreover, calms the water in the estuary, which is thus sheltered. Dredging or other works can also be carried out in shelter from the sea and the inroad of sand; and a roadstead or outer harbour is provided of the greatest value to navigation. Lastly, if the neck is made adequately narrow, as is assumed, it secures the estuary from the incursion of sea sand, or facilitates, as on the Gironde and the Tay, the discharge of the materials brought down by the river; and it produces a state of equilibrium which ensures the maintenance of the estuary.

The passage of the channel across the foreshore between the coast and deep water, causes the formation of a bank on the side from which the travelling sands come; and these sands, and the alluvium of the river form a sort of basin, as Mr. Guérard has pointed out in the case of the Rhone, which generally projects from the coast, and in which the channel prolongs itself. The sand driven by the waves continues its travel along the coast, in rounding the extremity of the basin which constitutes the bar. The arrangement of jetties at the mouth of a river, proposed by Mr. Bouquet de la Grye, Fig. 5, Plate 4, allows of this travel of sand not being stopped; but it cannot always ensure an adequate depth at the entrance for vessels of large draught.

By prolonging the training-walls by jetties out to a distance where the waves no longer affect the bottom, the depth of which varies with the exposure of the site and the height of the waves, the travel of the sand is stopped; but it accumulates against one of the jetties, and, causing a progression of the shore seawards, eventually comes round the end of the jetty. A method, however, of obviating this defect by groynes and the formation of land and dunes along the coast, has been described, Fig. 7, Plate 4.

The sand from the coast which arrives in front of the outlet of a trained river, comes in with the flood-tide; but the ebb carries it out to sea with the alluvium from the river, and it soon continues its travel along the shore. This assumes that the ebb current is as strong as the flood-tide, which explains the silting-up of estuaries too much expanded, or with too wide an outlet. It is, therefore, expedient to make the outlet of the trained channel adequately narrow, to prolong the jetties out to deep water, and to give them such an inclination to the general line of the coast that

the prevailing winds shall throw on to the shore the sands carried down the channel. If, in spite of the depth into which the windward jetty extends, the bar should be raised, it is advisable to prolong the channel seawards. It may even be expedient to make the end of the longest jetty project beyond the general line of the sands along the coast, since the sea maintains the depths round capes and projecting points of the shore. The Author, however, considers it preferable to arrest the sand, as previously described, before it reaches the trained channel; and the travel of the sand, which will continue below the channel, will gradually clear the mouth.

It is advantageous to place the outlet of a trained channel, in a funnel-shaped estuary, on the side of the entrance away from the quarter whence the sands arrive. But the best plan is to enclose such an estuary by breakwaters, leaving only a narrow outlet just sufficient to enable the flood-tide to fill the estuary. This system will be the more advantageous in proportion as the estuary is large, the tidal range higher, and the sea-slope steeper; and for the reasons already given, it appears preferable to training a river out to deep water, even in some cases lowering the bar outside to such an extent as to present no impediment to navigation, as at the outlet of the Tagus and the Foyle.

If a river flows only into a small estuary, or if there is no estuary at its mouth, an estuary can often be created by converging jetties projecting from the coast. This method has been adopted with success for the Liffey and the Tyne. As the outlet for the latter river projects beyond the general line of the shore, the maintenance of a suitable depth at the entrance of this new estuary will be more fully assured.

The Paper is illustrated by four sheets of drawings, from which Plate 4 has been prepared.

Discussion.

Sir Robert Rawlinson.

Sir ROBERT RAWLINSON, K.C.B., Vice-President, said members who had heard these elaborate Papers read would have a good deal to contemplate before they could come to any conclusion. They were exceedingly obliged to Mr. Vernon-Harcourt, who was an indefatigable worker—not speculative, but practical—for his Paper. Their thanks were also due to Mr. Partiot for the amount of matter he had brought forward. He (Sir R. Rawlinson) considered, however, that there was too great a mass of matter embodied in the Papers to be discussed with advantage, and that if they had had one-tenth of the matter abstracted and read, they would have been much better able to deal with it. Members might not agree with him in this; but, whether they did so or not, he hoped they would join in a hearty vote of thanks to the Authors of these very able Papers.

Mr. Vernon-Harcourt.

Mr. L. F. VERNON-HARCOURT said he had treated in his Paper on four distinct questions with regard to the training of rivers. Three of those subjects were not referred to in Mr. Partiot's Paper, which was confined to the fourth, viz., training-works in tidal estuaries. In order to compare the bars in the case of the Rhone, the Danube, and the Mississippi, the diagrams had been drawn to exactly the same scales. Diagrams were also exhibited of the estuary of the Seine, and the mouth of the Rhone. They were not inserted in the Paper, because plans of the delta of the Rhone, and also of the Seine estuary would be found in fairly recent volumes of the Proceedings.[1] The diagram of the Seine being the last survey made, namely in 1891, was exhibited for the purpose of comparison with the survey of 1875. The diagram showed the lines of sounding of 1875, and also the lines of sounding of 1891. Within that period, they had retrogressed seawards; and deep water was less near the estuary of the Seine than it was in 1875. It would hardly be right for him, at the opening of the discussion, to criticize the Paper of Mr. Partiot, which had been coupled with his own; but he might point out in what way he thought the Author wished his Paper to be discussed. He had had the opportunity of hearing Mr. Partiot express his views at

[1] Minutes of Proceedings Inst. C.E., vol. lxxxii. Plate 6; and vol. lxxxiv. Plates 4 and 5.

the International Inland Navigation Congress at Manchester in 1890, and also at the Paris Congress in 1892, that a narrow neck was essential for the proper training of rivers through estuaries. Mr. Partiot had been considering the subject for a great number of years; and one of the schemes which had been experimented upon in the models referred to, was a scheme brought forward by Mr. Partiot in 1859 for the completion of the Seine training-works. What Mr. Partiot would undoubtedly wish to be discussed was, how far it was desirable to narrow the outlet of an estuary in order to improve the navigable depth of its channels both above and below. Two illustrations might show what he really would advise. With regard to the estuary of the Ribble, which was funnel-shaped and something like the Seine, Mr. Partiot, if consulted, undoubtedly would recommend the construction of a breakwater from Southport towards St. Anne's, leaving a small neck near St. Anne's, or a breakwater in a reverse direction, starting from St. Anne's, and leaving a narrow outlet near Southport. Also in the case of the Loire, Mr. Partiot had suggested that instead of its being left as it was, it would be desirable to narrow the existing neck near St. Nazaire, in order to improve the channel in the estuary.[1] Those illustrations indicated the points that Mr. Partiot would wish to have discussed. Mr. Partiot had stated in his Paper that the ebb-tide formed the channels above the neck of an estuary, and the flood-tide formed the channel outside. He did not see how that could be accepted as the basis of an argument, because one of the channels above the neck was undoubtedly formed by the flood-tide, whilst the channel outside was mainly formed by the ebb. For instance, the Sloyne channel running up to Eastham, in the inner Mersey estuary, was due to the flood-tide; whilst the channel below Liverpool, out to the bar, was mainly maintained by the ebb. He would not, however, criticize the Paper at that stage, but would leave it to receive that full discussion by members that Mr. Partiot desired. Mr. Vernon-Harcourt.

Sir ROBERT RAWLINSON, K.C.B., Vice-President, said that the Papers were so elaborate, and so valuable, that they might be regarded rather for the purpose of reading than of discussion in detail. Mr. Vernon-Harcourt, one of their most valued members, had brought before them a very valuable Paper on the training of rivers; and Mr. Partiot had written upon the subject of Sir Robert Rawlinson.

[1] "Étude sur les Rivières à Marée et les Estuaires," H. L. Partiot, Paris, 1892, p. 87.

Sir Robert Rawlinson. estuaries. The French Government had paid much more attention to roads and rivers than the English Government had ever done; and there were, consequently, examples of national river-training, canal construction, and harbour improvement in France such as could not be paralleled in England. The English Government appeared to have given over everything connected with roads and rivers to individuals or companies. The only roads that had absorbed national attention were the main roads in Ireland and in the Highlands of Scotland, which were constructed through the interference, and by the aid of the Imperial Government. England was left to the tender mercies of Trust Boards. The first thing that an engineer would do, in considering so wide a subject as rivers and harbours, would be to examine the meteorology of the district, upon which harbours depended for their capability of being formed, and for their maintenance. Meteorology was a very wide subject, and yet its primitive elements were simple. They were three in number: the ocean, which provided the water to be evaporated; the sun's heat to evaporate it; and the atmosphere, to carry and spread the moisture over the surface of the globe. There was also another element that was seldom thought of or discussed, namely, the subtle and irresistible power of the earthquake. They had all heard what it had been very recently doing in Greece. Living comparatively securely upon their own little island, they were very much inclined to forget the gigantic forces that were only slumbering. In the comparatively quiet region of Great Britain, there were annually thirty or forty recorded minor shocks of earthquake, and they were not without some effect. Some scientific men had recently made a very delicate instrument with which to carry out their researches, and when they had perfected it they could not use it, because they could not find a single place on the surface of the earth—on the plains, at the bottom of coal-pits, or upon the mountains—where it could act in consequence of the incessant vibrations taking place in the earth's crust at every point where it was applied. Cuvier had stated that all the existing mountains—such as the great ranges of the Alps, the Andes, and the Himalayas, and all the active volcanoes, had broken the tertiaries, the tertiary formation being the last geological formation with which they were acquainted. That being so, it might reasonably be considered that, even in this period, they were not in a state of permanent repose. They knew very little of the past history of the world beyond a few thousand years, taking the Egyptian monuments as a record

Sir Robert Rawlinson.

Even if these periods could be multiplied by thousands, they would take us back a very little way into the history of the crust of the earth. They should remember that, while as engineers they were priding themselves—and properly—upon the magnitude of their works, and the efforts they were making to control nature, there was a point beyond which they could not expect to go, and that they must work in faith and leave the result to the future.

The training of rivers had not been carried out to any large extent in England, and there were many countries where it was not capable of being carried out to any great extent. In a country where the general surface gradients were steep, he did not see how river-training was to be thought of. In South Africa, for example—a country which should be the hope of many junior engineers—what could be done with the training of some of its rivers which rose in a week from their extreme low-water to 70 feet in height, and became roaring torrents? In Australia, again, for a series of years there might be no appreciable fall of rain upon the surface; and then a series of tornado rains producing roaring torrents occurred, so that rivers that had been dry for years rose vertically 120 feet, carrying off all that was in their way. The only method that an engineer could resort to in a country so situated would be to make somewhere, not much above low water, a track by which bullock wagons and other traffic could cross over in the dry season, as was done in Australia; and then a notice-board might be put up, similar to that of the Welsh engineer—"Take notice that when this bridge is under water this road is impassable." And not only was there that difficulty with regard to rivers, but, in the case of harbours and estuaries, there was the difficulty of the sea. Some years ago a book was written upon raised beaches, in which certain beaches were described which were considered to have been raised above the sea-level in consequence of a gradual rising of the land. The fact was that the sea could and did influence and destroy beaches, and also could throw up beaches which became dry land, from 12 to 30 feet in height, of which the Chesil beach was an instance. At its junction with the Isle of Portland, the beach was about 30 feet above high-water mark. When once in that district, he heard of a brig that was embayed there during a violent onshore storm, which the waves lifted up on the top of the 30-foot beach, and it was launched down over the other side. That showed that the sea was capable of making a beach which might deceive the embryo geologist. It was also well known that the sea could waste. If they examined old English maps of the east coast, the west beaches, or the south,

Sir Robert Rawlinson. it would be seen that within historic periods, parishes that were very large had either disappeared or had become very small. On the east coast, the rivers, with one or two exceptions, that flowed into the North Sea were mere stumps of rivers, whose estuaries had all been washed away. Geologists, in fact, stated that the North Sea was a very recent subsidence, and was a very shallow sea. They also said that at no very distant period, Great Britain and France were joined, there being no intervening English Channel. When these things were remembered, they should be very cautious how they entered upon reclamations for forming harbours, and should look carefully at what had taken place, and what might take place in future. He had recently read in *The Times* that the dredging of the channel of the Mersey had deepened it so much that vessels could now come in and go out which previously could not do so; and the reporter stated that he had no doubt that a permanent deep-water channel would be made by the process now going on; but knowing what he did of the estuary of the Mersey, he did not think that the improvement could be permanent. Some years ago he had occasion to hold an enquiry at Wallasey, and he then read the subject up; and having to make a survey of the coast, to see what encroachments had been going on, he found that within a century about 150 feet of the beach had been wasted. A lighthouse which had stood out upon this beach had been taken down; and if the embankment which the Corporation kept up was taken away, thousands of acres inland would be submerged, and the flow of high tides would be from that portion of the sea to, and through Wallasey Pool into the Mersey. In earlier periods there was a water connection between the upper portion of the Mersey estuary, through the lower parts of the Cheshire coast, into the Dee.

He had found that there had been an examination of the coasts of England during the Roman occupation by Antoninus, in which the adjacent rivers flowing down into the sea, such as the Conway and the Dee, and the Ribble and the other rivers northward, were mentioned, but no Mersey. He satisfied himself that at that period there was no direct flow of water from the inland estuary of the Mersey above Liverpool, through the great banks which now impeded the navigation of the river, which was at that time a huge salt marsh. The very name "Mersey" indicated what it was. The upper portion above Liverpool was the "Mere Sea"—"mere" meaning an inland lake—so called because it had no outlet past Liverpool. Liverpool was on the wrong side of the Mersey. If they had been fortunate enough to select the Cheshire shore, they would have had

deep water all the way down opposite the site of Liverpool, and would have been able to make entrances for their docks to any depth they chose; but now Liverpool was on a lee and shallow shore. The tide rose 20 feet above the old dock sill, and ebbed 11 feet below it. When he was connected with the docks, the deepest entrance was not more than 7 feet below old dock sill. Among the rivers that had been improved, the Clyde had been mentioned; and he wished to draw special attention to it, because he regarded it as very liable to be a misleader. Formerly there were only 3 feet of water from Glasgow Bridge to the sea, where there were now 29 to 30 feet, this depth having been gained by dredging and blasting. Glasgow was a large commercial and manufacturing city, which required a deep-water outlet to the sea. It could afford to form that outlet and to maintain it. But if from any cause the work of maintenance was stopped, the Clyde would very rapidly go back to its original condition, with a low-water depth not exceeding 2 or 3 feet. If any young engineer thought that he could deepen some other river in a similar manner, where there were not funds to pay for maintenance, he would only bring mischief and ruin to the place. Sir Robert Rawlinson.

He wished to refer for a moment to a great work that had been accomplished in their own day—the Suez Canal, which was a passage dredged between the Red Sea and the Mediterranean. It was a great work, but in itself a very simple one. It had been made by spending an enormous amount of money in dredging; and it still existed as a canal because large sums of money could be afforded for maintaining that dredging. If, however, the dredging were stopped, in ten or twelve years the canal would be choked up with sand. The subsidence of the banks and the rising of the bottom were natural evils which men could not control, except by incessant dredging. He had heard it said that the canal was not capable of taking all the traffic that now came upon it; and people had talked of doubling its width. His advice would be that they should do nothing of the kind. If further accommodation was required, a second canal should be made; because if they doubled the present canal, they would increase fourfold the difficulty of overcoming the rising of the bottom. With regard to the Seine, if anyone wanted to know the difficulties that an engineer must experience in working there, he should go and see the condition of the inlet to the Seine at high-water spring-tide, and watch the action of the bore, 10 or 12 feet in height, where the waves were thrown into confusion. Turner had painted a splendid picture which he had called "Quillebeuf," showing that contention of the

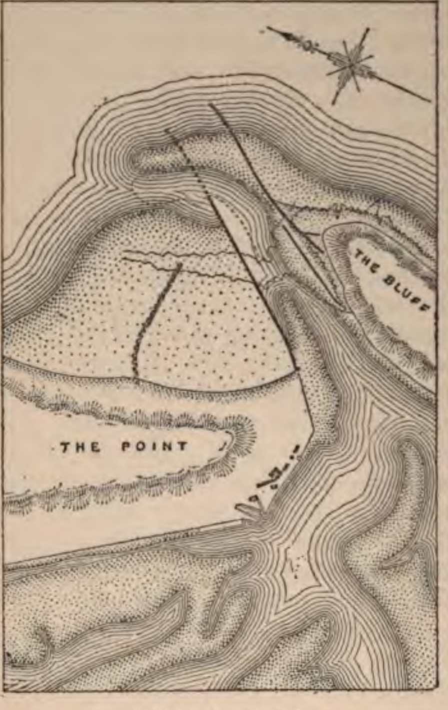
Sir Robert Rawlinson. sea, the waves dashing up, and the birds catching the fish as they were thrown out of the sea into the air. He would be a bold engineer who did much at Quillebeuf at the entrance to the Seine. With regard to harbours of refuge, they might go to the Channel Islands. England had done her best to make harbours of refuge there; but she had given it up in despair. It did not pay, and what had been done was simply lost expenditure.

Mr. O'Meara. Mr. P. O'MEARA said he wished to refer especially to the question of sand-travel, as opposed to the travel of detritus carried in suspension. There was a great difference between the two; and their being mixed up, he thought, had led to very great confusion, and perhaps to some errors, in the designs of ports. The travel of fine sediment in suspension was effected by the action of waves and currents; and it moved along coasts, down rivers, and through estuaries under those influences, deposition taking place whenever a check occurred in the velocity of the stream. The chief method, under those conditions, of improving a harbour was so to manipulate the currents as to prevent that check, and that deposition of sediment. Sand-travel was a totally distinct action, although there were features common to both. Sand-travel he held to be maintained by the joint action of waves and currents. Waves were of two kinds, namely, breakers, and waves of oscillation; and their action was somewhat different. Waves of translation turned into breakers as they approached the shore; and each breaker in falling dug a hole, or, at all events, slightly disturbed the sand. Immediately, the existing current shifted the sand a few feet or inches; and so the process of the action of the breakers on the sand, assisted by the current, went on. He had often seen long stretches of beach, after the retreat of the tide, pitted with holes, a foot or more in depth, in the manner described. The breakers themselves caused such a current; and those currents —whether littoral currents, or currents caused by the action of the waves of translation—carried on the sand so lifted for a few feet at most. But waves of oscillation had also a very powerful influence on the travel of the sand. The first observation which he made on the subject, fifteen years ago, would explain what he meant. In a narrow tidal channel at the entrance of Port Natal, wanting to observe for himself the action of the waves and currents on the sand moving in and out under the action of the tides, he went one day when there was a very slight tidal movement, the velocity not exceeding 6 or 8 inches per second. Not having a diving-dress, he dived to the bottom, with a good-sized stone in his hand, to assist his passage downwards,

and to have something to lay hold of and keep himself steady Mr. O'Meara. while making his observations. The small waves, not exceeding 6 or 8 inches in height on the top, produced a very marked effect upon the sand below, not only on a certain amount in suspension close to the bottom, but also on the sand lying on the bottom. He noticed as each wave was passing overhead, that the sand, instead of flowing along regularly, was oscillating. The sand rolling along the bottom, as well as that in suspension, was oscillating; and he judged that this was from the effect of waves overhead. At the centre of each passage, the velocity was very quick; and at a certain point it became quite suspended, and he almost thought it went backwards. He thought that explained clearly why a slow current, about 6 inches per second, could transport such sand, although it was well known that such a velocity was not capable of moving sand at all, unaided by a wave on the top. He wished to direct attention to the marked influence which even very small waves had in a depth such as that in which he made his observations—9 or 10 feet—in facilitating or causing the movement of sand at the bottom of rivers or estuaries. Judging from what he had observed, he should not be surprised if those waves produced movements at a much greater depth than 21 feet, which, he believed, was generally held to be the limit of the disturbing action of waves. He thought that the effect of sand-travel at much greater depths was very considerable. He thought that 40 or 50 feet was not too great a limit to assign. Even at that depth, he imagined, there was a very considerable movement of sand, when assisted by such waves acting simultaneously with the current. He should be glad if some engineer, who had electric light at his disposal, would extend the isolated observations he had made. By means of a glow-lamp, more knowledge on this point could be attained. The idea of the movement of sand by currents in conjunction with waves was of very easy application, and afforded an explanation of things that were almost impossible to explain by the movement and deposition of silt in suspension. The action of a groyne, for example, was much more easily understood when this idea of sand-travel was applied to it. There was retrogression on one side, and sanding-up on the other as a natural consequence. In the same way, it was evident why, at a bend in a sandy river, the sand was deposited on the convex side and removed from the other. It was simply due to a suspension in the movement of the sand, resulting in an accumulation on one side, and a consequent retrogression on the other, no interruption in the sand-travel occurring on the receding

Mr. O'Meara. side, because of the veering of the waves round the groyne. The effect of the bias of waves on a sandy beach, or of the angle made by their axes with the beach was also worthy of notice. He could point to an instance of such a bias acting in a very singular manner on the coast at Port Natal. The axes of the rollers radiating from the bluff changed their direction according as they moved round its extremity. The mere fact of this bias of the waves in breaking on the shore was sufficient to create a current which moved the sand in the opposite direction to the natural movement which would otherwise be caused by the prevailing currents in the immediate neighbourhood, a little distance out to sea. The Mozambique current passed along the coast nearly from north to south, but the sand moved from south to north; and he ascribed that almost entirely to the action of the bias of the waves. He had heard the late Sir John Coode describe this action, and he thoroughly agreed with him.

Fig. 1.



Scale 1 inch = 500 feet.

PORT NATAL.

Another point to which he desired to call attention was, that on long stretches of coast affected by a prevailing sand-travel, concave indents might be observed followed by convex prominences in the contours of the beach, and that these did not remain stationary, but travelled onwards in the direction of the sand movement. It would be possible to produce such a concavity by raking, or otherwise disturbing a short portion of the beach; a corresponding prominence would at once form on the forward side, and both would travel along the coast for an indefinite time, depending on

the influences at work in their course. Similarly, a prominence preceded by an indent, would be formed by projecting a temporary groyne or other obstacle from the beach, just as the water of a river would be raised behind, and lowered in front, for a short time, by a temporary dam, on the removal of which, a wave would be propagated down the stream. Mr. O'Meara.

The baneful tongues of sand which stretched across the mouths of rivers and estuaries on sandy coasts, also travelled in a very remarkable manner. At Port Natal, for instance, the tongue which had now projected itself northward from the bluff, across the outer end of the unfinished works, *Fig. 1*, and which had been drawn into the channel to a certain extent by the inflowing tides, assisted by breakers veering round the present end of the south breakwater, was in existence, somewhat further in, long before the construction of that work. It used to extend itself northward along the line of the bar, pushing before it the navigable entrance channel across the bar, till it reached a point about 50 or 100 yards northward from the loose stone groyne shown on *Fig. 1*. By this time it became cut through at its root, opposite the centre of the straight channel; and immediately the northern channel, at the tip of the tongue, became sanded up, and a new tongue commenced to project itself northwards from the bluff, pushing the new channel onwards as before. This occurred sometimes in less than a year, but frequently took a much longer time. Such tongues receded when the sand-travel was reversed, another tongue advancing from the opposite direction. Small travelling rills or ridges, with a steep slope on the forward side, and a flat one behind, were, as far as his experience went, the invariable concomitants of all sand-travel, except where breakers were at work. When observed in the entrance channel at Port Natal, they were about 6 inches high and 6 feet apart or more, with a depth of water of 9 feet, waves 6 to 8 inches high, and a current of about 6 inches per second.

Whilst agreeing with Mr. Partiot as to the beneficial effects of curved jetties, of moderate length, at the mouth of a river or estuary, receiving the ebb currents on the concave face of the jetty which was on the side nearest to tho approaching sand, he could not endorse generally his recommendation of groynes, as typified in Fig. 7, Plate 4. He did not doubt that it was possible to divert, though not to arrest permanently, a sand-travel, by promoting the formation of dunes by means of groynes, as proposed by Mr. Bouquet de la Grye, and palisades movable vertically, as carried out successfully by Mr. Chambrelent at the Bay of Arcachon ; but a heavy sand-travel, of a thousand cubic yards or

Mr. O'Meara. more per day for instance, would soon occupy too much space in the vicinity of the jetties if diverted into dunes; and the proposed groynes would be extremely expensive on a sandy beach at exposed places. The bluff ridge at Port Natal, south of the entrance, was a sand dune 7 or 8 miles long, about 300 feet high, and of very old formation. The beach of limestone, however, on which it rested, seemed to have been raised at least 20 feet above sea-level by elevating forces. There were recent sand dunes on the coast of Brazil, which were half a mile broad or more, 260 feet high in places, and extended for hundreds of miles with occasional interruptions.

He had now sufficiently explained the processes of sand-travel by under-drift, as distinct from silting or over-drift, to enable any one to apply them to the statements and descriptions of Mr. Partiot. He had done so himself very carefully with reference to the works recommended for the improvement of the Seine estuary, and found no difficulty in agreeing with the greater part of Mr. Partiot's very concise and intelligible observations. He recognized the advantage of a neck, at, or near the end of an estuary, and thoroughly approved of a contracted entrance as far seaward as possible, with training-walls diverging up-stream therefrom, both of which must tend to diminish the influx of sand, and also of a gradual widening of the channel of a river in its descent, in order to benefit from the resultiug regularity in the flow of the stream, and from tidal propagation.

Mr. Shelford. Mr. SHELFORD said that the great number of facts contained in the Papers would be useful to the Institution for years to come, because those who had to study the questions concerned would be more likely to draw a correct conclusion from a large number of facts than from a few isolated ones. He believed that during all the years they had discussed rivers and estuaries in that room, they had never defined what an estuary was from an engineering point of view. Even Mr. Partiot, an old and distinguished French engineer, had commenced his Paper by a definition of an estuary. He had stated that "Estuaries are inlets on or near the sea-coast, containing banks which the tides successively cover and lay bare." That was a very vague and unsatisfactory definition of an estuary, because it only dealt with the visible effects of the forces at work, and ignored their cause. He then went on to say that they might be divided into two classes, viz., "estuaries devoid of rivers, and estuaries into which rivers flow." Estuaries devoid of rivers were rather uninteresting to engineers; whilst estuaries into which rivers flowed were full of engineering operations, and were of

great importance to them. He would suggest as a proper definition Mr. Shelford. of an estuary, that it was an arm of the sea having more than one tidal channel. To make the point clear, he would refer to the river nearest at hand as an example, viz., the Thames, which was divided into three compartments—the estuary, the tidal river, and the non-tidal portion. The tidal portion—to say nothing about the non-tidal—had but one channel, up and down which both the flood and ebb passed, and produced the most perfect condition which the circumstances would allow, so that they had a first-class tidal river. But immediately below Sheerness, where the estuary commenced, there were several channels; the main flood-stream came up one, and the main ebb-stream went down another. The consequence was that the flood-tide tended to carry detritus up the river, and the ebb in the other channel tended to carry it down the river, so that there was a continual shifting of sands between the two, a state of things common enough in other estuaries. The Mersey had been also mentioned several times as a very interesting example. The upper estuary of the Mersey extended from Liverpool to Runcorn; the tidal wave was impelled through the channel at Liverpool on to the Cheshire side of the Mersey; and the flood-tide, by its own momentum, travelled along the line of least resistance to Runcorn. The difference of level between the two points was, of course, the same for the incline on the Cheshire side, and that on the Lancashire side; but as the Cheshire side was 50 per cent. longer than the Lancashire side, the greater declivity was on the Lancashire side. The normal result was that the ebb-tide necessarily flowed down the Lancashire side, because it was the shortest route. It was a principle that should not be ignored in all estuaries, that the ebb-tide always took the shortest practicable route to the sea. This he could illustrate in a very simple way. If they stood on a sea-shore, the wind blowing obliquely, and the waves coming obliquely upon the beach, each wave could be seen coming up in the direction in which it was driven; but it invariably retired at right angles, being the shortest route to the water. The tidal wave acted much in the same way. A great deal might be said about Mr. Partiot's view as to the importance of necks, whether artificial or natural, at the mouths of estuaries; but he would not go into the subject, much less generalize upon it, as by far the safest practice was to judge each case upon its merits. He thought that the definition he had given of an engineer's idea of an estuary, and the principle of the ebb-tide taking the shortest route to the sea, where it was possible to do so, were perfectly

Mr. Shelford. safe and sound engineering. Mr. Vernon-Harcourt had referred to the London International Maritime Congress, in which he had taken an active part. What had struck him (Mr. Shelford) at that Congress, was that the improvement of entrances to ports was now very largely performed by suction-dredging. It appeared that the ports on the coasts of France and Belgium were being improved in that manner. Undoubtedly, the best example of that kind of dredging was on the Mersey; and it had been so far successful. The last accounts showed that the depth over the Mersey bar had been doubled. In America, also, they had been doing a great deal in the way of improving their harbours by suction-dredging. To those who had been accustomed to look upon training channels as the only means of getting rid of sand-banks, it was a novelty to find suction-dredgers taking the work out of the hands of the trainers.

Mr. Wolfe Barry. Mr. J. Wolfe Barry, Vice-President, as one of the British representatives on the International Technical Commission of the Suez Canal, would like to correct an idea of Sir R. Rawlinson's, that the question as to whether the canal should be widened, or two canals formed was now under consideration. That matter had been settled, after a very considerable conflict of opinion, about six or seven years ago. The British representatives, Sir Charles Hartley and the late Sir John Coode, with others, were strongly of opinion that the canal should be widened, in opposition to the scheme which was energetically supported by many foreign engineers, that two canals should be made. The widening had been in progress ever since, and was a great success both from an engineering and nautical point of view. None of the difficulties which Sir R. Rawlinson feared had been experienced; and the amount of subsidence of the banks, and raising of the bottom had been very trifling. The work of dredging for the maintenance of the canal was not great, certainly not nearly so great as was anticipated by many engineers in the earlier years of the canal, and did not weigh at all heavily upon the company. The chief amount of dredging took place in the outlet-channel at Port Said, where considerable dredging was required, giving rise to anxiety from time to time. The entrance was protected on each side by two long piers, which had been prolonged beyond their original length; and it was foreseen by many engineers, including the late Sir John Hawkshaw, who reported on the subject in 1863, that there was a risk of the sand, drifting eastwards, accumulating on the western side and overlapping the entrance; which had to some extent taken place from time to

time. The piers being in rough water, exposed to winds and storms, dredging beyond their extremities proved troublesome and expensive; but the growth of the deposit had of late years been to a very great extent arrested by the removal of the crest of the west pier near its shore end. The upper part of the pier having been thus lowered in different places from time to time, the sand consequently came into the channel where it could be dredged, instead of accumulating beyond the pierheads. The dredger working in comparatively smooth water, there was no difficulty in dealing with the deposit. The work had been in progress for some years; and he believed the whole Technical Commission were completely satisfied that this difficulty had been overcome, and that they might be certain that the mouth of the canal could be satisfactorily kept open, and, in fact, deepened. Also, apart from the widening of the canal, a great additional depth had been given at the same time. On the strong representations of the British representatives, the canal was now being carried to a depth of 28 feet; and it was hoped that before long there would be a depth of 29½ feet from shore to shore. He had mentioned these facts because he thought there might be some apprehension, from Sir Robert Rawlinson's remarks, of a risk to that important water-way from the widening. Instead of there being any risk of the bottom rising, a greater depth was really being gained than had previously existed; and the depth would be increased from time to time, so that the water-way would be very greatly improved by the works now in progress. Mr. Wolfe Barry.

Mr. E. D. MARTEN said that he had recently carried out a small, but successful training-work upon the semi-tidal portion of the Severn, a few miles above Gloucester. The Severn Commissioners had been improving the navigation of the river for some 30 or 40 miles; and among other things, they had had to increase the navigable depth of the river, from a minimum of 6 feet at low summer level, to 10 feet. For the most part, a certain amount of dredging merely had been required; but there had been some rather difficult places to deal with, one of them at Wainlode, 6 miles above Gloucester, where there was an awkward bend, the bed of the river consisting of hard marl rock. The rock shelved down to the convex side of the bend, so that on the concave side there were only a few inches of water at low summer level; while formerly there was barely a depth of 6 feet on the convex side. Floods and freshets coming down the river, impinged on the concave side; and consequently the old channel, on the convex side, was almost always impeded by silt, and was very Mr. Marten.

Mr. Marten difficult to keep open; which difficulty would have been much increased after deepening the channel from 6 to 10 feet. It would have been very expensive to make a cutting with a 10-foot face through the rock on the concave side, as the channel was 300 feet wide round the bend, though only 150 to 200 feet in width above and below. A training embankment was, therefore, formed on the concave side, to divert the floods and freshets on to the convex side, and so scour out the proposed 10-foot channel, by sinking a number of old canal boats end to end along the line of the river face of the proposed embankment. These boats only cost about £5 each, and were sunk in such a position that their tops just stood above the water at low summer level. They were held down by short piles driven into the marl rock, and were filled with the rock which was dredged from the channel. The whole of the space at the back of the boats was also filled with dredged marl rock. These works diverted the ordinary summer flow down the new channel, but this flow alone was not sufficient to keep open the new dredged channel. Accordingly, in order to direct the flood waters also down the new channel, five cross-dykes were made, such as Mr. Vernon-Harcourt had referred to in his Paper, by placing an old boat on the newly-formed embankment, nearly at right angles to the stream, and depositing over it the hard marl rock dredged out of the channel, and so forming a mound at each place. The dykes pointed slightly down-stream, and not up-stream as in the case described by Mr. Vernon-Harcourt. He thought it would be interesting to know what the advantage was of making them point up-stream. If it caused silting to take place between the dykes, it would be very advantageous, because it was expedient that the spaces between the dykes should fill up and become solid land. The trainimg embankment and the dykes had kept the channel perfectly free from silt, which had been kept dredged 10 feet deep, and with a face of from 4 to 6 feet through the hard marl rock round the convex side. That channel had now been completed for more than a year; and when he went over the site a few days ago, wherever he dropped a sounding-rod on the floor of the new channel, it gave out a hard, ringing, metallic sound, showing that the whole of the dredged channel was as free from sand and silt as the flagstones in Westminster Hall. That same channel, when the depth of water was 6 feet only and before the training embankment was made, used to be a constant source of anxiety and trouble, owing to the manner in which it silted up. On the Severn they had to be very careful to place nothing in the river which would tend to increase at all the floods on the meadow

lands above. That difficulty was got over here, partly by the increased sectional area resulting from the dredging, and partly by the improved hydraulic mean depth which was obtained; so that, notwithstanding the loss of sectional area caused by the embankment, the channel was now more capable of discharging floods than it was before the works were undertaken. The only anxiety they now had about the matter was, that for about 50 yards at the tail-end of the improved channel, a little bed of sand and silt tended to form. If this shoal should increase, it would only be necessary to carry the embankment on for a very short distance, because 20 or 30 yards past where the little shoal was forming, the river became 20 feet deep, and there was no danger of any further deposit. Mr. Marten.

Mr. G. F. Deacon remarked that the importance of making observations concerning the transport of sand by running water had been referred to by Mr. O'Meara. He had conducted a series of such observations for the Mersey Docks and Harbour Board, in connection with the Manchester Ship-Canal Bills of 1883–4–5, the results of which he would endeavour to summarize. Many abortive trials were at first made; but an apparatus was ultimately devised which enabled him to obtain perfectly trustworthy and conclusive results. The observations were made in a long flat-bottomed trough with glass sides, by means of which the behaviour of the sand could be accurately observed. The sand was from the estuary of the Mersey, the quantities moved were weighed, and the surface velocities of the water were carefully measured. When water flowed with a steadily increasing velocity over a surface of such sand, fine pieces of broken shell were first moved; and the surface velocity required to produce such movements was considerably less than 1 foot per second. At such velocities, however, the sand proper was perfectly stable, and however long the flow continued it remained undisturbed; but the fine pieces of shells at the surface of the sand moved in spasmodic leaps, accumulating wherever the velocity was somewhat less. Mr. Deacon.

The first movement of sand began at a surface velocity of 1·3 foot per second. This movement was confined to the smaller isolated grains; and if the same velocity was maintained, the grains so moved ranged themselves in parallel bands perpendicular to the direction of the current, each band taking the form of the well-known sand ripples of the sea-shore or sand-bottomed stream, with its flat slope upwards, and its deep slope downwards in the direction of the current. At this velocity the profile of each sand ripple had a very slow motion of translation, caused by

Mr. Deacon. sand particles running up the flatter slope and toppling over the crest. The steep downward slope was therefore being constantly advanced at the expense of the denudation of the less steep upward slope. At a surface velocity of 1·5 foot per second, the sand ripples were very perfect, and travelled with the stream at a velocity of about the $\frac{1}{2160}$ part of the surface velocity of the water (*Figs.* 2 and 3). At a surface velocity of 1·75, the ratio

Fig. 2.

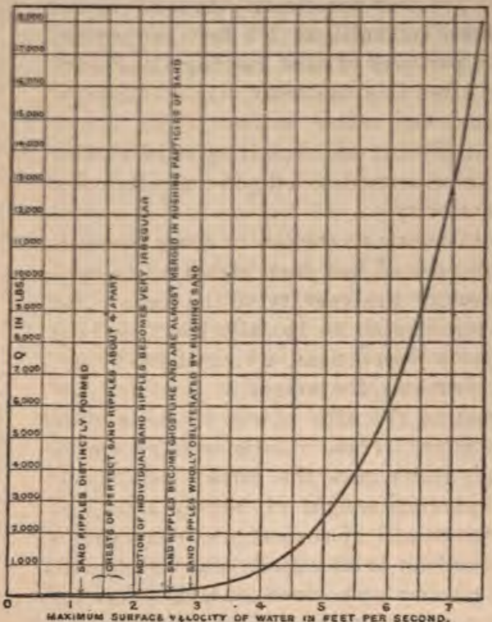
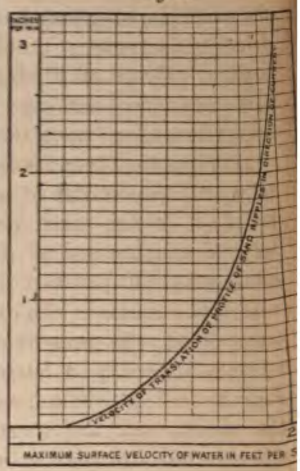


Fig. 3.



NOTE.—Q is the weight of sand which, in a channel of uniform velocity, is capable of being moved across any section per hour, per foot-width of stream. If, at the rate Q, the supply of sand is maintained up to the given section at the up-stream end of the sand-bed, the same weight will be continuously discharged at the lower end of the sand-bed without any change of section. An increase of velocity at once deepens the section throughout until another condition of stability is reached, which will be maintained so long as the new value of Q is supplied at the upper end of the sand-bed.

was reduced to about $\frac{1}{1050}$, and at a surface velocity of 2 feet to $\frac{1}{480}$. A critical velocity was reached when the surface of the water moved at 2·125 feet per second, when the sand ripples became very irregular, indicating greatly increased unsteadiness of motion of the water. Up to this point, the whole amount of scour was represented by the volume of the sand-waves multiplied by an exceedingly low velocity, always less than the $\frac{1}{480}$ part of the surface velocity of the water. At about this critical velocity of

2·1 feet per second, the particles rolled by the water up the flat slope, instead of toppling over the steep slope, were occasionally carried by the water direct to the next crest; and as the velocity of the water was gradually increased, an increasing bombardment of each crest from the crest behind it took place. At about 2·5 feet per second, another critical velocity was reached, and many of the little projectiles cleared the top of the first, or even of the second crest ahead of that from which they were fired. At surface velocities of 2·6 to 2·8 feet per second, the sand ripples became more and more ghostlike, until, at 2·9 feet per second, they were wholly merged in particles of sand rushing along with the water in suspension. After this the scour was of a totally different character; the sand and water became mixed, and a constant process of lifting, carrying, and depositing of individual particles ensued, the sand being stirred to a depth and lifted to a height dependent upon the velocity. Mr. Deacon.

Attempts had been made to determine the law of scour theoretically, and the weight of sand moved had been stated to be proportioned to the sixth power of the velocity of the water. He believed the method of determination to be fallacious; and the result was not justified by his observations, which showed that, within the limits of the experiments, the weight of sand and silt transported was proportional to the fifth power of the surface velocity, possibly a little more. These results were shown in *Figs.* 2 and 3. The larger curve gave the surface velocity of the water, and the corresponding weight of Mersey sand and silt scoured from the up-stream end of a shoal, and conveyed in the direction of the stream, so long as its velocity was maintained. Under each condition of velocity and corresponding weight of sand moved across any given section, a uniform channel was maintained.

In considering the effect of proposed works, it seemed to him of the utmost importance to have regard to the fifth powers of the observed or probable resultant velocities, as the case may be, at various cross sections. For example, it could be shown to be impossible, in the present condition of the Mersey estuary, for any permanent deposit to occur opposite Liverpool; but it could also be shown how exceedingly small a loss of tidal capacity, in he basin of the upper estuary, was necessary to so far reduce the velocity at cross sections above Liverpool, as to cause the banks now exposed at half-tide to creep down towards the deeper channel between Liverpool and Birkenhead, and thus in their turn to aggravate the reduction of capacity and reduce the scour of the bar. He had

Mr. Deacon. specially applied this mode of investigation to cross sections of the Mersey, but it was equally applicable to other cases.

The general result of this investigation, involving the fifth power of the velocity, applied to sand or silt of all degrees of fineness, and he believed (within the limits of surface velocities up to 10 feet per second) to all depths also; but the actual quantity of sand or silt transported depended upon the size of the individual particles, and upon the depth of the water.

The absolute weights, therefore, of material given were only true under the conditions of the particular experiment in question; and they might be much larger in practice, especially where, as in the case of the Mersey, enormous quantities of fine silt were held in suspension up to the surface of the water, and where, during each spring-tide, no less than 100,000 tons of solid matter were brought into the estuary, while on the ebb a corresponding quantity was again returned to the sea.

Mr. Vernon-Harcourt. Mr. L. F. Vernon-Harcourt, in reply, said that Sir Robert Rawlinson had referred to geological changes, but he thought that engineers must be content with things as they were at the present time, and leave to their successors to deal with whatever changes they might afterwards find. The French engineers had been bold enough, more than a quarter of a century ago, to carry the Seine training-works beyond Quillebeuf, in spite of the difficulties described by Sir Robert Rawlinson. Rather more than ten years ago, he had, in a discussion in that room, expressed the opinion that the widening of the Suez Canal would be in every respect preferable to the construction of a second canal;[1] and he was glad to hear from Mr. Barry that it was being accomplished successfully. With regard to material in suspension, and material which was travelling along at the bottom, both were found in the Mississippi and the Rhone. There was in most rivers, no doubt, some material that was carried in suspension, and some material that was rolled along the bottom. In most cases, the material that was rolled along the bottom was more difficult to deal with in these rivers than the material in suspension. In the case of the Rhone, in going over from the Port of St. Louis to Marseilles, in a steamer, though they were some distance from the mouth of the Rhone, they came across the layer of yellow alluvium from the river in suspension on the surface; and by the stirring up from the screw of the steamer, the bluish waters of the Mediterranean could be seen underneath. Mr. O'Meara had, however,

[1] Minutes of Proceedings Inst. C.E., vol. lxxvi. p. 239.

referred more to the travel of sand along the coast. In the case of tideless rivers, the material was brought down by the rivers themselves. Generally, the travel of sand along the coast depended mainly upon the direction of the prevalent and strongest winds in the locality, because the winds raised the waves, and the waves carried the material along the coast. In dealing with any harbour or river, the direction of travel, the density, and the amount of the material should be considered. Mr. O'Meara had also mentioned that he thought the movement of material was supposed only to occur down to a depth of 21 feet. In a Paper which Mr. Vernon-Harcourt had read before the Institution in 1873, upon Alderney Harbour, he had mentioned that he had found, as far as one could judge, that the movement of the rubble base of the Alderney breakwater ceased at a depth of something like 21 feet below low water.[1] He had, however, heard since then, that at Tynemouth the movement of rubble and large blocks took place at even a greater depth. Sand was a very different thing from rubble; and if rubble could be moved by waves at 21 feet below the surface, no doubt sand could be moved at a considerably greater depth. Mr. O'Meara approved both of funnel-shaped estuaries, and also of estuaries with a narrow neck. There might be cases where a narrow neck was advisable, but generally speaking one could hardly approve of both those systems of training-works for improving an estuary. Mr. Vernon-Harcourt.

The difficulty as to the definition of estuaries had been mentioned by Mr. Shelford. In Section 4 of the International Inland Navigation Congress at Paris in 1892, they had proposed to define estuaries, but they had been unable to arrive at a satisfactory agreement on the subject. They came to the conclusion that they could not define an estuary, but that everybody knew what an estuary was.[2] Then with regard to the question of the ebb-tide, mentioned by Mr. Shelford, taking the shortest direction. He quite agreed with him as regarded the Mersey that the flood-tide ran up the Sloyne Deeps towards Eastham, and that the ebb-tide generally skirted the opposite shore. In the case of a winding river it would be found that the ebb-tide followed the sinuosities of the river, and that the flood-tide took a somewhat straighter course, because the ebb-tide followed a course corresponding to that of the ordinary discharge of a river without any tide, whereas the flood-tide would flow up in a different, and somewhat straighter

[1] Minutes of Proceedings Inst. C.E., vol. xxxvii. p. 74.

[2] V^{me} Congrès International de Navigation Intérieure, Paris, 1892, Procès-Verbaux des Séances des Sections, p. 596.

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Mr. Vernon-Harcourt. course; and, as he had mentioned in his Paper, blind channels would be found in many wide tidal rivers, which were due to the flood-tide, the main low-water channel being due to the ebb. [Mr. SHELFORD said he quite agreed as to rivers, but he had spoken of estuaries.] He (Mr. Vernon-Harcourt) was thinking of a river with which he had had to do—the Usk, though the wide outlet of that river could not quite be called an estuary—where the flood-tide could be seen forming blind channels. Even in a wide estuary, however, the ebb-tide could not be said to take invariably the shortest route to the sea, for the low-water ebb-tide channel wandered about all over a wide estuary in its constant alterations of course. Thus, in the inner Mersey estuary, though the low-water channel was usually near the Lancashire shore, it ran close along Ellesmere Port, on the Cheshire shore, in 1875; and, in the Seine estuary, the main low-water channel was sometimes close to Havre, and at other times close to Honfleur on the opposite side of the estuary. The course of the flood-tide was influenced by the direction in which it approached an estuary, and by the form of the estuary; whilst the ebb-tide, though impelled by gravity, and therefore tending at first to adopt the straightest course to the sea, was soon diverted, as the tide fell, into the deep low-water channel, which constantly shifted under the action of winds and the erosion of sandbanks; and the main object of training-works in an estuary was to direct the flood- and ebb-tides into one channel.

With regard to Mr. Marten's question about the dykes in his case pointing down-stream, and in the case of the Rhone pointing up-stream, he must mention that the dykes that pointed up-stream in the Rhone were dipping cross-dykes. The reason why they were made, practically in every case, pointing up-stream, was, he believed, in order to make the current converge towards a central channel, because the great object on the Rhone, when there was very little water, was to get a deep channel, and as much water as possible into the centre of the river.

Narrow necks had been advocated by Mr. Partiot because, from a study of estuaries, he had found that they were the best for estuaries. On previous occasions when Mr. Partiot had quoted the Mersey at international congresses, Mr. Vernon-Harcourt had suggested that he thought English engineers would hardly quote the Mersey as an instance of a satisfactory estuary. With regard to Mr. Partiot's proposal with reference to the Seine, the objection was this, that if a narrow neck were formed at the mouth of the Seine, putting aside all questions of expense, by the making of a breakwater from Villerville

nearly to Havre, a large quantity of material would be brought in in suspension, through the narrow neck, as he had himself seen it on the Havre side of the estuary. That material would be carried up the estuary by the rapid current through the narrow neck, would settle in the estuary as the current slackened, and by degrees silt up the sluicing basin formed by the enclosed estuary. Undoubtedly Mr. Partiot would get a large depth in the narrow outlet of the river, and probably would maintain it for a considerable time; but he proposed also to put training-walls into that estuary. Now Mr. Partiot had stated in his Paper, that he quite agreed with the English engineers that it would have been undesirable to carry out those training-walls in the Mersey which were proposed for the Manchester Ship-Canal in 1883 and 1884. If Mr. Partiot agreed with the view that it would be a disadvantage to put training-walls in such a situation, Mr. Vernon-Harcourt should have thought Mr. Partiot must admit that, in the case of the Seine, training-walls put into the estuary, after it had been converted into an estuary with a neck, would produce the same results, and that the estuary of the Seine would gradually silt up. Mr. Partiot had also referred to the works at the mouth of the Tyne and the Liffey, which he called artificial estuaries. Converging breakwaters in those situations Mr. Vernon-Harcourt thought no one could doubt were very satisfactory. There was a sheltered place formed where the bar could be dredged away, as had been done in the case of the Tyne; or, as in the case of the Liffey, it was possible by concentrating the tidal currents at the outlet to scour away a certain portion of the bar. The artificial estuary of the Liffey, as it was called, had been increased in tidal capacity by dredging inside the estuary itself; therefore it had been possible, in this case, to maintain the tidal capacity of this artificial estuary. But that, in his opinion, was quite a different thing from converting a wide estuary into an estuary with a narrow neck. Mr. Vernon-Harcourt.

Another subject to which Mr. Partiot had referred in his Paper was the improvement of rivers by dredging, which he seemed to think was undesirable. On the other hand Mr. Vernon-Harcourt believed the results of recent works tended to show that dredging could be carried on economically and advantageously to a far greater extent than formerly. Dredging, as stated at the London International Maritime Congress last year,[1] had been carried on successfully so far upon the Mersey bar, which

[1] International Maritime Congress, London, 1893, Section I., Minutes of Proceedings, p. 60.

Mr. Vernon-Harcourt. was so much exposed, that if anywhere dredging might not be supposed to be likely to be successful it would be there. They had been able hitherto to lower the bar considerably in a somewhat narrow channel; and, provided they had sufficient funds to continue to carry out those works, there was no reason why they should not be able to maintain an improved navigable depth over the bar. It was a question of maintenance; and until the bar had been lowered to the full extent that was necessary, it was impossible for anybody to say how much that maintenance might be. Nevertheless he believed it would be an advantage to Liverpool, not merely in deepening the channel across the bar, but also in maintaining the position of the navigable channel, which, as they knew, tended to shift; and, by deepening it, the main channel would tend to remain in the deepest part. When it was remembered what had been done upon the Clyde, and still more what had been done upon the Tyne, it must be acknowledged, in spite of Mr. Partiot's views, that dredging, as well as training-works, afforded a most valuable means of improving rivers.

Mr. Partiot. Mr. H. L. PARTIOT desired to reply first to Mr. Vernon-Harcourt, who had recalled the fact that, at the International Inland Navigation Congress at Paris in 1892, he had expressed surprise that the Mersey was cited as a good river, whereas it was one of the worst estuaries that could be named, and that a bar existed at the end of its outlet channel. He (Mr. Partiot) did not think that he had ever stated that the state of the Mersey was satisfactory; but he had pointed out at the congress that the existence of the bar did not invalidate the law which he desired to verify, and in accordance with which a channel had been formed below the neck, extending 9½ miles beyond Liverpool with depths of 33 feet.[1] This law was, that in estuaries with a neck, a great depth was found in the neck itself, and also deep channels, extending generally to great distances from the neck, both into the estuary and also towards the sea. This natural fact was proved by observations of this class of estuary, of which he had given fourteen examples in his Paper. He could add sixteen others, namely, Western Port, Corner Inlet, and Port Phillip in Australia, the Bay of Richmond in North America, Malamocco in the Adriatic, Mitindani in South Africa, Exmouth in England, Dornoch Firth and Loch Fleet in Scotland, Lorient estuary in France, the Minho and Mondego rivers, and the Bays of Setuval and Portimaon in

[1] V^me Congrès de Navigation Intérieure, Paris, 1892, Procès-Verbaux des Séances des Sections, pp. 621, 622.

Portugal, the Cameron river on the west coast of Africa, and the Rio Grande do Sul in Brazil; and there must be many more which he did not know. With the exception of variations due to local causes, all these thirty examples conformed to the law which he had indicated. The instances of estuaries devoid of rivers which he had cited, showed that the law did not depend on the rivers which flowed into the estuaries, but on the existence of a neck. These estuaries, however, had not appeared to enterest engineers, because ports could be established on them, like Poole Harbour; or sometimes even these kind of estuaries could be artificially created for the requirements of navigation. The estuaries to which he had referred had existed since prehistoric times, although the entrances of most of them were exposed to the inroad of sand; and experience thus proved that these estuaries maintained themselves, or only filled up extremely slowly. This was readily explained, for in a funnel-shaped estuary, the flood-tide flowed in over all the width of the entrance, bringing in sand along this great extent; and the ebb-tide dispersed itself over this same width, and lost the greater part of its power to carry back the sands to the sea. When the entrance, however, was narrowed, the sands could only come in along a less length of beach, and the action of the ebb was concentrated for throwing back the sand on the coast; and there was a certain width of neck for which this concentration sufficed to carry out to sea, not merely the sand brought in by the flood, but also the materials brought down by large rivers, such as the Garonne and the Dordogne. If, therefore, a neck was formed at the entrance to an estuary, it was certain that its effects would be in conformity with the same laws as those which had been manifested by the examples he had given, namely, a great width in the neck, deep channels of a considerable length, both above and below the neck, and the maintenance of the estuary with silting up. A bar might be formed inside estuaries, as found in the Foyle near the Flats bank, and in the Gironde above Richard; and it would therefore be advantageous to construct training-walls to lead the river beyond this bar, within the zone of action of the neck, as shown in Fig. 9, Plate 4. A directing training-wall might be useful beyond, to guide the channel, or to prevent its wandering away from a port on the shore. It might also be expedient to form a false channel outside the regular channel, whose wanderings might combine with the other causes in keeping down the level of the sandbanks; though the Jude estuary, and Arcachon Bay proved that this was not indispensable. The aim of his Paper was to deal merely with the theoretical

Mr. Partiot.

Mr. Partiot. question of the improvement of estuaries. He must, however, remark that an investigation of the subject, quite independent of the question of the Seine, had led him to propose a system of improvement for estuaries, Fig. 9, Plate 4, which much resembled the scheme which other considerations had caused him to prepare for the Seine.

Both observation and calculation proved that contractions did not prevent the discharges of tidal rivers and estuaries from increasing continuously down to the sea, and that necks did not appreciably impede the influx of the tide into rivers and estuaries. Observations taken on the Garonne indicated that high water of springs and neaps reached the same level at Bordeaux as at Pointe de Grave; and the low-water line at spring-tides was only about $1\frac{2}{3}$ foot higher at Bordeaux, whilst at neap-tides, it was about $3\frac{1}{4}$ feet lower there than at the mouth of the Gironde. The tidal action, accordingly, was not hindered by the neck at Pointe de Grave. Calculations furnished evidence of this fact, for the best formula for the average velocity of the flow of a river, was $U = \sqrt{\frac{h\,I}{l}}$, deduced from Prony's formula, which showed that in two equal rectangular sections, with equal slopes, the discharges varied up to a certain limit as the square roots of the depths; and the depths in the neck at Pointe de Grave reached about 100 feet below zero. Lagrange's formula also, $K = \sqrt{g\,h}$, giving the rate of propagation of waves, showed that these velocities followed nearly the same laws. The great depths of necks, therefore, explained why necks of suitable width and depth did not offer any serious obstacle to the discharge of the water flowing into and out of an estuary, or to the propagation of the tidal wave up a river. His observations on the Gironde, given in a previous publication,[1] showed that the velocity of the currents in necks was not a hindrance to navigation, because the neck was scoured, and the section thereby increased, when this velocity exceeded a fairly moderate limit.

He had pointed out in his Paper that a current which passed from a narrow neck into a much wider space lost its velocity, and exerted only a feeble scouring action on the bottom immediately in front; and he had explained how the channels above and below the neck were due to the drawing of the sand towards the neck. The Rio Grande do Sul in Brazil appeared to him to give a striking illustration of this fact, where depths of $16\frac{1}{2}$ feet did

[1] "Etude sur les rivières à marée et les estuaires," H. L. Partiot, Paris, 1892, p. 58.

not extend more than 2 miles below the neck, the rise of tide being Mr. Partiot. only 2 feet; whereas depths of over 33 feet were found up to San Juan del Norte, 8 miles above the neck. On the Mersey, where the river was small, and the tides had a large range, the channels of the upper estuary were short, whilst the outlet-channel had great depths for over 9 miles.

Much time had been devoted by Mr. Vernon-Harcourt to small-scale models, with which he had carried out experiments in relation to the Mersey and the Seine. The model experiments undertaken at Rouen had furnished results which were only imperfectly known; but nevertheless he could say that those which had been ascertained had varied considerably, according to the duration of the experiment, and the manner in which new sand was placed in the model. He thought that Mr. Vernon-Harcourt would have obtained different results with his model if he had continued each of his experiments for a longer period; and he would, therefore, urge the importance of the precautions necessary, in using small-scale models, to obtain useful results.

His definition of an estuary had not been considered sufficiently exclusive, and consequently as somewhat vague. He was fairly in agreement with Mr. Shelford on this subject; but it seemed to him necessary to furnish a definition, because some engineers did not consider the inner estuary of the Mersey above Liverpool, and the estuary of Lorient above Port Louis, to be estuaries. On the other hand, some wide spaces inland, such as the branches of the Odet below Quimper, and Lédanou were true estuaries. A definition of estuaries proposed at the Paris Congress of 1892 by Mr. Mengin-Lecreulx had been rejected, and only applied to estuaries with rivers. His definition, however, was general, but did not include the wide spaces in rivers where the tide did not leave extensive sandbanks uncovered at low water; and, such as it was, he considered it worthy of acceptance.

Correspondence.

Mr. N. DE SYTENKO observed that, whilst acknowledging the Mr. Sytenko. clear views expressed by the eminent Authors, felt bound to raise some minor objections. He did not consider it right to take the Rhone regulation works as a model of the system of improving the navigable condition of the principal rivers of Europe, though the Rhone had, indeed, been improved by means of submerged dykes, in conjunction with parallel training-walls, so that a

Mr. Sytenko. minimum depth of 4½ feet had been obtained in place of 1½ foot, which was the available minimum depth up to 1876. The physical conditions, however, of the Rhone differed materially from those of most of the European rivers which had been greatly improved within recent years. The average fall of the Rhone being 1 in 2,000 between Lyons and its mouth, was much larger than the fall of the Elbe, the Oder, and the Weser; and its rate of flow also, which amounted in some places to 20 feet per second, was decidedly greater than that of the other rivers of Europe. The small discharge of the Rhone, moreover, and its relative uniformity during all the period that navigation was practicable, and the solidity of its banks, caused the alluvial matter brought down by the river to be of a hard nature, the greater portion of which reached the sea without disintegration. The success of the Rhone regulation works possessed at the time an importance, owing principally to regulation, in this special instance superseding canalization, which till then had been considered the most efficient method of improvement, though also the dearest. In fact the Rhone, in the central portion of its course, might be said to lie between two groups of rivers, one of which required to be improved by canalization and the other by regulation. On the other hand, when, within the last ten years, the improvement of the great rivers of central Europe was undertaken, which had a very sluggish flow and a moderate fall in a sandy stratum, it became necessary to modify the regulation works. The engineers, relying upon theoretical considerations in their schemes of improvement, tried to form a normal channel which should contain all the water discharged at a given section, whilst preserving the requisite depth for navigation. It was hoped that this channel might be formed by half cross-dykes, starting from the banks and from longitudinal training-walls submerged during floods. Later on it was realised that the object had been only half attained, and that to secure a complete improvement, it was essential, in forming the normal channel, to take into account the minimum summer discharge, as well as the average discharge. During the low stage of the river, the trained channel should direct the current so as to afford the necessary navigable depth along the whole length of the navigable river; and this depth being generally secured during the period of average discharge, the changes in the channel produced during its somewhat prolonged period had a great influence on the depth. Accordingly, the destructive and creative power of the current of average discharge should be employed, by means of suitably designed

training-works, for the formation of a proper channel. The Mr. Sytenko. problem was considerably complicated in dealing with a river of such a unique character as the Volga in its central portion; and if the system of regulation adopted for the improvement of the great rivers of central Europe was applied to the Volga, the expense would be enormous, whilst success would be doubtful. The Volga, indeed, surpassed all the other European rivers, both in its gigantic dimensions, and the immense quantities of silt which it was constantly shifting; and, consequently, irrespectively of the cost, its improvement involved a much more complicated problem than any works hitherto carried out on the other European rivers, and one which the most eminent Russian engineers had not yet succeeded in solving.

He was fully convinced that, in this case, experiments made in imitation of those which Mr. Vernon-Harcourt had so ingeniously carried out in his investigations with regard to the outlet of the Seine, could not fail to lead to positive results. Mr. Vernon-Harcourt, however, had to deal with tides, which he could reproduce with tolerable facility; whereas a tideless river, like the Volga, was quite a different matter. The deposits produced in Mr. Vernon-Harcourt's model, corresponded to some extent to the phenomena which actually occurred in the Seine channel, both in its open, as well as in its trained portion. Those results were obtained by imitating mechanically the flow and ebb of the tide; but the difficulty of imitating, in a model of limited size, the displacements of deposit which produced the shifting shoals of the Volga, was all the greater since the changes in the velocity of the current occurred very rarely, though generally regularly and during a fairly long period.

As he was himself proposing similarly to carry out, on simplified models, the experiments necessary to investigate the possibility of arranging fixed groynes in a movable bed for the purpose of intercepting the silt and alluvium carried down by the current, which was more rapid at the summit of its parabolic course, and removing the deposits by constant dredging with a suction dredger, he must acknowledge the great difficulty of establishing clearly certain laws as to the formation of those deposits. Nevertheless, it was very desirable to investigate the subject of the formation of deposits in the channels of non-tidal rivers by the experimental method, which, as proved by Mr. Vernon-Harcourt, gave fairly positive results, and not merely theoretical, in the case of tidal rivers. So long as the laws concerning the deposit of silt and alluvium carried down by a river were not established on a

Mr. Sytenko. tolerably incontrovertible basis, it would be difficult to give the preference to the views of either Author as to the improvement of estuaries; but, nevertheless, it was sometimes of great importance to take account of the velocity of flow of a river.

Mr. Willcocks. Mr. G. W. Willcocks remarked that, in the improvement of rivers, navigation, arterial drainage, and water-power were always considered. The fisheries, however, at times of more value than all these three, appeared to be totally lost sight of. Rivers should be as valuable for producing food as the farms on dry land; and the engineer should, therefore, know enough of the natural habits of the different fish to avoid injuring fisheries by the improvement of rivers; and he should try to improve the propagation of the useful species without unfairly interfering with other interests. The idea that river fishing was only for the pleasure of a few rich sportsmen was most misleading. Civilised countries would not expend large sums of money on fishery boards and inspectors if this were the only result. The salmon fishery of the Tay was worth £70,000 per annum, that of the Shannon probably £40,000, and of other rivers in proportion. The eel fishery alone of Lough Neagh and the lower Bann was worth at least £6,000 per annum. For the sake of fisheries, shallow margins to rivers should exist in some form. In salmon rivers, gravel shoals and shallow margins were the spawning grounds, which should always be covered with water not less than 4 inches deep. If the water subsided, so that the spawn and young fish were left high and dry, they were naturally destroyed. On the other hand, if the water was too deep, the ova might become sterilised. Therefore, in removing gravel shoals, shutting out shallow margins and encouraging accumulation thereon, and cutting off secondary channels, the reeds or nests of the salmon were lost. If no compensation were given, the fisheries would decrease greatly in commercial value. The velocity of the river, increased in times of flood, might disturb, or sweep away the spawn deposited in the gravel. Elvers also, on their way up from the sea in spring, always kept near the banks, to avoid a strong current, against which they were unable to swim. For these reasons, continuous training-walls, rising above the level of the dry-weather flow in the non-tidal parts of a river, as being carried out on the Rhone, were detrimental to the propagation of migratory *salmonidæ* and other useful fish. In the Rhone and other Mediterranean rivers, no salmon existed, owing to the temperature of the sea, so that the above remarks were not so strongly applicable to them. But for most rivers flowing into the Atlantic and Pacific Oceans, not nearer

the Equator than 40° latitude, it seemed doubtful whether the works on the Rhone should be taken as an example. Mr. Willcocks.

Mr. J. V. Wilfrid Amor remarked that, in a modern work on geology a principle was very clearly explained—which had not been alluded to in the present Paper, nor in previous Papers on cognate subjects—in the following extract translated from the French:—"The accumulation of sediment (at the bottom of the sea) is helped by the property possessed by sea-water of retaining fine matter in suspension for a much shorter time than fresh water does. Thus, according to Mr. Sidell (quoted in Dana's 'Manual of Geology'), sea-water clears itself in fifteen times less time than river-water does; notwithstanding that, on account of its greater density, it causes bodies immersed in it to lose one-fortieth more of their weight. By experiments Mr. Sidell proves that precipitation which required ten to fourteen days to be completed in fresh water, took place in fourteen to eighteen hours in saline solutions."[1] In consequence of this principle, if a river of given volume of flow, bringing down a certain amount of alluvial matter in suspension, with a given velocity, discharged into a fresh-water lake; while another river, exactly similar, discharged into the sea, the result of the precipitating power of salt water would be that the alluvial matter would be transported to a fifteen times greater distance in the lake than in the sea. Anyone studying the two deltas without taking this principle into account, would be very much at a loss to explain their totally different characters. When a tidal estuary was full of salt water at high tide, the sediment brought down by a fresh-water stream discharging into it was almost at once deposited, not only on account of the reduced velocity, but much more perhaps on account of this precipitating power of salt water. This principle accounted to a great extent for the very beneficial effects of training-jetties at the mouths of rivers; because, by keeping the river-water separate from the sea-water for a greater length of time and space, they prevented the matter in suspension from being precipitated close to the mouth of the river. Mr. Amor.

He could testify from personal experience to the inconvenience caused by the want of training-jetties, as he had been stranded for a whole tide on a mud-flat at the mouth of the Mississippi in 1876, before the late Captain Eads had carried out his great work.

[1] "Traité de Géologie." M. Lapparent. 1882. Première partie. Livre deuxième. Section I, p. 169.

Mr. Amor. Also in 1872 he witnessed the painful anxiety of the crowd of spectators on the old pier at Portugalete, when in rough weather a ship in distress attempted to cross the bar of the Nervion. Both the inconvenience and the danger had now been done away with by training-jetties.

Mr. Corthell. Mr. E. L. CORTHELL said, with reference to the Paper on "The Training of Rivers," that the facts and general conclusions were important and valuable, and would be of great use to the engineer engaged on river and harbour works. There were, however, some few statements and conclusions which he felt obliged to controvert. It was assumed by Mr. Vernon-Harcourt that the Gulf of Mexico was a tideless sea, and that the Mississippi and other rivers entering it were tideless rivers. Comparatively speaking it might be possible to so consider it, as the mean range of the tides did not exceed 14 inches in any part of the Gulf of Mexico; but there were tides of much greater range occurring every month, and sometimes sufficient to produce a considerable current at ebb-tide, and they were all useful in assisting to make and maintain the channel between training-works. An examination of the tidal range given in his "History of the Mississippi Jetties" would afford an idea of the force of the tidal currents a times.[1] He had personal knowledge of the tidal conditions a several points on the Gulf of Mexico, notably at the mouth of the Mississippi, the Brazos River, the Aransas Pass, th Panuco River, near Tampico, Mexico, and the Coatzacoalcos Rive on the Isthmus of Tehuantepec. It might be assumed that ther was an effective range of 2 feet for scouring the river-bed an the bars at the mouths of the rivers in the Gulf of Mexico. No must it be supposed that all the rivers emptying into the Gulf o Mexico were delta rivers. The Brazos, Panuco, and Coatzacoalco discharged their waters into the sea through one mouth; an the bars in the sea had not advanced materially beyond the shore line of the country. In fact at Coatzacoalcos, the record betwee 1871 and 1892 showed a recession of the sea-face of the bar.

Mr. Vernon-Harcourt, in forming his conclusions as to th effect of jetties at the mouths of rivers in the Gulf of Mexic and elsewhere in comparatively tideless seas, had based the upon a misapprehension of the conditions, for he stated "dens matter, rolled along the bottom, soon comes to rest when th current is checked on emerging into the sea, and mainly form

[1] "A History of the Jetties in the Mouth of the Mississippi River," E. I Corthell, p. 227.

the bar which is invariably found in front of delta outlets." It was evident that he had assumed certain statements to be correct which were made in public documents prior to the construction of the jetties at the mouth of the Mississippi River. These statements were proved to be erroneous by Mr. J. B. Eads, the projector of these works. The discussion in the controversial literature of that time was summarized in the "History of the Mississippi Jetties" (pp. 24–49). It was there shown that very little material was rolled along the bed of the Mississippi River, in its lower reaches at least, and that the bar was formed almost entirely from the deposit of sediment held in suspension during the progress of the river towards the sea, which was dropped on account of the loss of velocity of the issuing current, spreading out fan-like over a semi-circular area. This sediment was dropped on the outer contour of the circular bar; the finer sediment being often carried by the diminished current far out to sea. Mr. Corthell.

He must also take exception to the detailed statements and the chart which accompanied Mr. Vernon-Harcourt's Paper. This chart showed that the 30-foot channel was discontinuous; and while this was a fact, and the statement in the Paper was correct, yet the result as exhibited on the chart was temporary, and such conditions were only occasional, and not the normal conditions of the channel. The contract of Mr. Eads with the United States Government required that the channel should be made and maintained for twenty years, 26 feet deep and 200 feet wide at that depth, with a central depth of 30 feet without regard to width. With rare exceptions, during the fifteen years since this channel was obtained by the jetties and auxiliary works, the full size required had been maintained. It would be very difficult to maintain a channel by a natural current, the widths and depths of which should at all times comply with the arbitrary enactments of a law. This channel might be deeper than the law required, and slightly narrower; or it might be slightly shallower, and much wider. The dredging done from time to time was mainly for the purpose of making what was at all times a sufficiently large channel for navigation conform to the exact requirements of legal enactment. The normal conditions of the channel were shown in a chart in the report of the Chief of Engineers, United States Army, for 1893, where the 30-foot channel was continuous, and at least 100 feet wide. Mr. Vernon-Harcourt spoke of the necessity at one time of dredging the bar beyond the jetties, where there was only about 26½ feet of water. At the time, however, there was a 30-foot navigable channel, but not in the direct prolonga-

Mr. Corthell. tion of the jetties; and a channel was dredged for the purpose of opening a new channel in this direction. The condition of the bar then existing, which had made this dredging advisable, had appeared only once or twice during the last fifteen years, and was caused by "sand-waves," which occasionally during the flood season travelled down the river, past New Orleans, and dividing at the head of the passes into three divisions, went to the sea through the three main outlets of the river. During the passage of the sand-wave through the south pass, there was likely to be a temporary shoaling, which the natural forces dissipated as soon as the sand-wave passed into the gulf. The peculiarities of this condition were fully described in the reports of the Chief of Engineers, United States Army. It was expected by Mr. Eads, and by all who were connected with the works, that the delta would constantly advance into the gulf, and that the time would come, considerably remote however, when an extension of the jetties would be required. The fact that they had served their important purpose for fifteen years, with a probability that without any material extension of the works and with very little dredging, either in the jetty channel, or in the sea beyond it for a long period of years to come, was sufficient reason for having expended a moderate sum of money upon the construction and maintenance of the works. In order that there might be no misapprehension as to the amount of dredging required beyond the ends of the jetties in the gulf, the following extract was given from official records:—

DREDGING DONE BEYOND THE ENDS OF THE JETTIES.

1891.		1892.		1893.	
January . .	1 day	August . .	4 days	January . .	5 days.
August . . .	6 days	September .	9 days	May . . .	3 days.
October. . .	1 day	December . .	4 days	August . .	2 days.

In a Paper which he was preparing for the Institution on the works constructed upon his plans, and under his charge, at the mouth of the Panuco River in Mexico, some of the important conditions and questions brought forward by Mr. Vernon-Harcourt in his Paper would be fully stated, and the general conclusions would be based upon twenty years of professional work along the shores of the Gulf of Mexico.

Mr. Luiggi. Mr. L. LUIGGI, Engineer-in-chief of the harbour works at Leghorn, observed that the two Papers under discussion were of the highest interest, and marked a distinct stage of progress in the

study of the physical features of rivers and estuaries; matters that were formerly accounted for in a dubious or tentative manner being now, in most cases, explained on well-reasoned and clearly-established principles. There was, however, in both Papers one point not clearly defined, for it was practically assumed that the bars or shoals formed at river-mouths or estuaries were produced mainly by the materials deposited by the waters of the river itself. This was not precisely the case, as proved by many examples. There were channels of perfectly clear water, such as the Sile, near Venice, the Canale dei Regi Lagni, near Naples, and the Viareggio Canal, near Leghorn, the outlets of which were completely barred; also the channels between the Venetian lagoons and the sea, through which the sea-water was perfectly clear, were silted up to within 8 or 10 feet of the surface. On the other hand, there were many rivers heavily charged with solid matter, such as the Humber, the Severn, and the Thames, in none of whose estuaries were any serious obstructions found. It was, therefore, evident that the matter brought down by a river was not the only factor to be considered in the formation of the bar. The action of the waves in conveying material along the shore, and depositing it in any adjacent bay or inlet, had an important bearing upon the case. This effect was very distinctly traceable at Viareggio, where there were two jetties, between which a depth of 8 or 9 feet of water was maintained by constant dredging. Every time, however, that a storm came from the south-west, although the channel between the jetties might not be affected, the mouth was silted up to 5 or 6 feet. Mr. Luiggi.

Other phenomena tended to prove that the formation of a bar depended mainly upon the action of sea waves. The fresh water of a river flowing out into the sea formed, according to its force or velocity, a sort of barrier or liquid jetty, which acted almost like a solid jetty in stopping the travel of suspended matter along the shore. The matter thus arrested gradually accumulated against the liquid jetty, forming a kind of sandy groyne, and slowly deflected the outgoing current. This was very evident, for the rivers flowing to the North Sea through Germany and Flanders could not alter their northerly direction so long as they passed through mountainous districts; but as soon as they reached Holland or Belgium, where the rivers were free to flow into the sea in any direction, their outlets trended uniformly to the south-west, because the prevailing waves were from north-north-west. The more violent the waves, and the more perpendicularly they struck the shore near the outlet of a river, the greater was the

Mr. Luiggi. direction is governed by that of the prevailing waves, which accords more or less with that of the prevailing winds.

It was clear that the proportionate effect of the direct bottom wave and of the return wave varied with the slope of the sea-bottom and the resultant direction of the gravitating force of the deposited or suspended material. The river or estuary current tended to diminish the force of the inward wave, and to augment that of the return wave, and so far helped to disperse towards the open sea the materials brought down the channel itself. The ebb and flow of the volume of tidal water which had to pass over a given point, also tended to neutralise the accumulation of material and to maintain a certain proportionate depth. Further, the ebb and flow were not always of equal duration. In many places the former occupied much longer time; and in such cases the solid matter being longer exposed to the return waves, the tendency was to scour this solid matter towards the open sea, while at the same time the neutral line was deflected nearer the shore. This necessarily facilitated the scouring work of the return bottom wave in maintaining the free waterway of the estuary.

The experience of Italian hydraulic engineers might be thus summed up: that the estuary or mouth of a river would keep itself free of all deposit if the neutral line passed within the estuary or mouth itself; and that under the contrary condition, there would be a continual tendency to silt up. In such cases no permanent improvement could be effected, except by constructing jetties on each side of the channel to extend beyond the neutral line. The Tees, the Tyne, and the Liffey were instances in point, and also the Venetian ports of Malamocco and Lido. In the latter, the scour obtained by extending the jetties into depths of 20 to 25 feet, or slightly beyond the neutral line, had increased the depth of the waterways from 8 or 9 feet to 25 feet, and in some places up to 30 and even 39 feet. The Sulina mouth of the Danube presented similar features, the neutral line being at about 20 feet below the mean sea-level; while in the South Pass of the Mississippi the corresponding depth was between 23 and 30 feet.

If the coast was in process of erosion there was naturally little tendency to the formation of a bar; but if the shore was silting up, the deposit would accumulate behind the windward jetty, and the neutral line would gradually be shifted seawards until it passed beyond the head of the jetty. The direct bottom wave then acquiring the preponderance, the channel itself would commence to silt up again unless the protective works were extended beyond the new position of the neutral line; but each

at least a certain period of time, it could not be conceded that it Mr. Luiggi was sufficient to extend them to "where the waves no longer affect the bottom," because it was essential that the waves should affect the bottom. Otherwise the alluvium would simply be deposited at this point, and the useful effect of the jetties would be lost. If in such cases no bar could be formed, it was because the waves did affect the bottom with a prevalence of the return bottom wave, causing the alluvium to be carried out to greater depths in the sea. In connection with this, it was useful to refer to the studies of Parodi, Mati, and Cornaglia, which formed so perfect a complement to the earlier experience of English hydraulic engineers. The results of these researches might be thus expressed: (*a*) the undulatory movement of the sea generates an oscillating bottom wave, alternately towards and from the shore; (*b*) under the crest of a surface wave, the bottom wave moves toward the shore, while under the hollow it returns outwards; (*c*) the force of the bottom wave increases with the height of the surface wave, with the increased 'fetch' or distance from which the waves arrive, and with the depth of the sea at the point considered; (*d*) the energy of bottom waves may be considerable at great depths; (*e*) on a submerged rising bed, the force of the inward bottom wave is greater than that of the return wave; (*f*) matter upon the sea-bed is struck alternately from opposite directions; (*g*) the component of the weight of this matter parallel with the bottom slope may counterbalance the effect of the direct or inward bottom wave, or add to the effect of the return bottom wave, so that the force of the latter is practically in excess. Thus on a flat shore the waves have a tendency to wash the materials towards the shore, and to silt up the beach; while on a steep sea-bottom the return waves prevail, and the materials are carried out to greater depths, and the tendency is to erode or denude the beach; (*h*) the points at which the reciprocal effects of direct and return bottom waves, combined with the component of the specific weight of the alluvial matter, are counterbalanced, form the neutral line; (*i*) the greater the force of the waves, the flatter the slope of the sea-bed; and the less the specific weight of the suspended material, the deeper is the position of the neutral line. In the Mediterranean, this depth varies from 27 to 33 feet; (*j*) landward of the neutral line, the bottom waves carry the materials toward the shore; seaward they draw them to greater depths; (*k*) parallel with the beach, the materials travel in the same direction as the waves. With alternate sets of the waves they accordingly travel one way or the other; but their ultimate

Mr. Siccama. in that case be specially considered. It was difficult to lay down hard-and-fast rules and formulas for the treatment of rivers, like recipes in a cookery book, although this had often been attempted. There were as many systems as there were rivers; what was a success on the Rhine might fail on the Danube, and excellent results were obtained on the Rhone by works impossible on the Mississippi. What was told them in the Paper under consideration made one wish for more information. The Rhone in particular, with its torrential floods and sometimes sudden subsidence, was a most interesting river to observe, and, from an engineering point of view, most attractive. Flowing, however, into a tideless sea, the mouth was not more complicated to deal with than the upland parts. It was where the tides had to be reckoned with that the problems become very intricate. Not only the quantities of water to be dealt with were larger, but the conditions were various and conflicting. The works required to obtain any effect were costly; and if found not to answer, as costly to alter or to remove. Works intended to improve the navigation through an estuary might have the effect of reclaiming land, and be fatal to the original object. Many instances of this might be adduced. For instance, in a case where the entrance was narrow, so as to obtain a greater scour over the bar in one spot, there the depth was increased; but two bars were formed, one outside and one inside the entrance, and the area enclosed gradually silted up, which again reduced the mass of tidal water oscillating in the enclosed space. It was often overlooked that in an estuary the deepest passes could only be maintained if the tidal wave could enter unchecked. The deepening was done by the flood-tide, as in most cases the flood slope of the tidal wave was steeper than the ebb slope. The greater its mass, the greater its living force and its maintained velocity, and the shorter the period of slack water during which suspended matter precipitated. If it was not feasible to give general rules for the maintenance of upland rivers, it was even more impossible to do so for estuaries. The only hint for guidance generally applicable, was not to obstruct the ingress or egress of the tidal wave, or to deflect suddenly its direction away from the estuary, or from its deepest channel. The velocity with which the flood entered an opening in the coast-line was not due solely to gravitation, but also to the living force heaped up in the wave. An instance in point was the new mouth of the Maas, where the old mouth, near Brielle, was the survival of the fittest pass, those to the north of it having gradually silted up. It was the free and untrammelled entrance

of the tide, as it came up from the south-west out of the English channel, which kept this pass open. Now, instead of assisting the natural forces in this channel, it was decided to reopen a channel on the site of those silted up ages ago, at right angles to the littoral currents. Of course the results did not answer expectations. The entrance jetties, instead of scooping up the incoming tide, and leading it inwards with its undiminished velocity, had their opening nearly at right angles to the direction of the flood current; and the power of the inflowing flood was due to gravitation principally, losing much of the living force of the wave sweeping past. Besides this, four varying conditions had to be dealt with during each tide:—(1) the flood rising at sea, with a current setting north and the river still ebbing; (2) flood at sea still rising with a northerly set, and running up easterly in the river; (3) ebb at sea with a southerly current, and a current still going up for a short time; and (4) ebb at sea with southerly current, and ebb in river. To these might be added the slacks of high and low water; and all these were again complicated by the differences in the strength and direction of the winds, and the quantities of upland waters discharged. The littoral currents, being nearly at right angles to the jetties, impinged on the obstructions, caused eddies, and formed pools near the jetty-heads. The flood current being the strongest, the deepest pools were found on the north sides of the jetty-heads; and the deepest water in the entrance, or the fairway, passed through the pool north of the jetty, and not being in the centre of the entrance, caused the fairway higher up to curve fantastically. It was only by continual and costly dredging that a sufficient depth could be maintained. The late Captain Blommendal of the Netherlands Royal Navy, and hydrographer-in-chief, repeatedly drew attention, while the new plans were discussed, to the dangerous experiment; but his very experienced advice was not listened to, owing to his differing in political opinions from the parliamentary promoters of the scheme. Now, however, those who had a practical interest in the matter had begun to see that an error had been committed. Some who had full local knowledge and experience averred that, should dredging be stopped, the cows would be able to walk across after a twelvemonth. At all events, the pass was not kept sufficiently deep by scour alone as had been expected. Estuary improvements being a hazardous undertaking, the prudence of the Mersey Dock and Harbour Board must be commended, as they were content to keep the required depth on the Mersey bar by the vast dredging operations which they were at

Mr. Siccama.

Mr. Siccama. present carrying out. With regard to Mr. Partiot's Paper, it might be said, that although precedent for the improvement of estuaries was seldom of great value, the success of the proposed works on the Seine mouth between Havre and Berville appeared problematical. They produced the impression that they would tend more to the reclaiming of land in the estuary than to the obtaining of a good tidal fairway. In the same way, if on the coast of Gascony, the flood came up from the south, a cut across the neck separating the inner basin from the sea at Arcachon might not give satisfaction; and the best course might be to assist the fittest surviving channel now running in a south-westerly direction. Working models of tides might give some information, in a general way, as to their action on solids of special conformation; but large allowances must be made for different or exaggerated dimensions, and the logical deductions from such observations must be accepted with caution. The temporary or trial-works spoken of were more trustworthy. Similar screens of wattling or fascines fixed against piles had frequently been used with satisfactory results by Captain Eads and his engineers on the South Pass, and by others on the higher reaches of the Mississippi near and above Memphis. The best way, however, to study an estuary was with the sounding-line in hand during all states of tide and weather.

Mr. Caland. Mr. P. CALAND was of opinion that the sectional area of rivers generally should be increased gradually downward, or funnel-shaped, so as to compensate for the gradually decreasing surface gradient, and the consequently diminishing velocity. Below the tidal limit this increase of sectional area should continue at a higher rate, so as not only to accommodate the ebb of the tidal water, but also the volume of discharge of upland water, arrested by the preceding flood-tide. Besides this, the river-mouth should be prolonged into the sea, by dams or jetties, to a point where the littoral currents were more sufficiently powerful to prevent the deposit of solid matter in front of the mouth. Where the quantity of solid matter brought down by the river was very great, the littoral currents might be deflected seaward, and it would then be necessary periodically to prolong the jetties. The sea, moreover, in many instances, tended to heap up materials along the coast-line, by which outlets might be closed; but if the discharge seawards could be maintained as the strongest influence, the heaping-up action of the sea could be counteracted. It was also very important, particularly on tidal rivers, to avoid straight reaches, as they provided no security for the fixity of the fairway.

A series of curves in succession appeared to be the most satisfactory. It was also highly important that the flood- and ebb-tide should follow the same deep-water channel, so as to avoid shoals between the two channels, which were always inconvenient for navigation. Changes in the river-bed should always be closely observed by continual sounding and velocity measurements. This was particularly required after high floods and ice, when unexpected and extensive deposits were liable to occur, requiring immediate removal by dredging to avoid inconvenience to the navigation. Mr. Caland.

With regard to Mr. Partiot's reference to the River Maas, he would observe that Fig. 12, Plate 4, was misleading, as the reclamation there shown was not due to the new works, for those areas were warped up ages ago in this formerly very wide estuary. Also the width from the mouth upwards and through the Scheur branch had been decreased regularly, so that the funnel-shape was maintained far inland. The depth in the new mouth was at present over 26 feet at low water, and about 33 feet at mean high water. He would refer to his book[1] on tidal rivers for a more exhaustive treatment of the subject under consideration.

Mr. G. van Diesen.

Mr. G. VAN DIESEN submitted as his opinion, based on observation, that where a river's normal discharge was not increased in volume by confluent rivers, such a river did not require a progressive increase of width downwards for the maintenance or increase of its depth. Only below the point where other rivers discharged into it was a widening desirable, to avoid a dangerous rise of the river in times of considerable discharge.

Where a river flowed into a tideless sea, the decrease in the surface-gradient where it approached the coast would cause a diminution of velocity unless the water was prevented from escaping sideways. By preventing this lateral escape by maintaining a uniform width, the velocity of the current would be maintained, and consequently the depth. The depth at sea in front must determine the length of the jetties at the mouth; but the width between these should in no case be increased, so as to prevent the sediment forming shallows in the wider part.

Also for tidal rivers, he considered a seaward widening of the mouth objectionable, as it checked the conveyance of matter in suspension toward the deep sea, forming a bar, or in favourable cases a delta. For the improvement of a river flowing through

[1] "Études sur l'Effet des Marées dans la partie maritime des Fleuves," Paris, 1861, P. Caland.

Mr. G. van Diesen. a delta, the several superfluous passes should be closed, and the undivided current directed through the pass most advantageously located. This was nothing else but abstracting the unnecessary width from the river. The widening of the mouth of a river towards the sea was often recommended for the free entrance of the flood-tide. Admitting that the entrance of large volumes of the flood-tide was favourable to a strong discharge during the ebb, it was not clear why a gradual narrowing of the river-bed inland should be considered to aid this, for a widening downward was a narrowing upwards; whereas, in his opinion, widening inland would be preferable and more favourable to the free ingress of tidal water, although there might be circumstances under which additional space for the flow of high tides or the discharge of upland waters might be desirable.

Mr. Stierle. Mr. A. Stierle remarked that though there were no rivers nor estuaries in the district under the charge of General W. F. Smith, U.S. Army, of such magnitude as those cited in the Papers, what was lacking in size was amply made up in numbers. This district embraced all the rivers and harbours on the western shore of Delaware Bay, and on the eastern shore of Chesapeake Bay, as far north as the latitude of Wilmington, Delaware, and those on the Atlantic coast between Cape Henlopen and Cape Charles, the whole being known geographically as "the Peninsula;" which was indented by innumerable streams and bays, especially on the Chesapeake Bay side. The streams of the Chesapeake shore, from Cape Charles to the mouth of the Susquehanna River, had a remarkably uniform rise and fall of tide at their entrances, varying only a few tenths of a foot above and below the average of 2½ feet; whereas those on the Delaware side had a rise of tide increasing steadily from 4 feet at Cape Henlopen to 6 feet at the mouth of Christiana River. Along the Atlantic coast, between the capes named, it varied between 3 and 4 feet. All the rivers on the Chesapeake Bay entered the bay through wide funnel-shaped estuaries, the smallest only of which were obstructed at the entrance by bars of littoral drift, caused by the currents being too feeble, and the volume of backwater too small to prevent their formation. The channels within the rivers were generally broad and deep as far as the tide flowed. The rivers in Delaware, however, were narrow, shallow, and tortuous, and without exception flowed into the bay through narrow outlets, and across a very flat, shoal foreshore, upon which the course of the channel could scarcely be traced, so that their entrances were navigable only at high tide. Whilst the streams on the Chesapeake side

were bordered but little with marshes, those in Delaware flowed through wide expanses of marsh land, recent deposits of alluvium, overgrown with salt grass and reeds, and often covered by the waters of storm-tides. The formation and outline of the Delaware marshes clearly indicated that they occupied the place of former estuaries now almost entirely filled up, and that a greater movement of sedimentary matter, both during flood- and ebb-tide, took place in the Delaware Bay than in the Chesapeake Bay. Mr. Stierle.

With one or two exceptions, the commerce on the rivers that had been improved by the United States Government in this district was comparatively small, and the improvements were made mainly for the purpose of creating a new branch of commerce, or of largely augmenting that which existed. As the dredged channels served the demands of a coastwise or a local trade, their dimensions were restricted, in proportion to the present and prospective commerce of the localities, to a depth of 6 to 15 feet at mean low tide, and to a bottom width of 60 to 300 feet. Since the question of cost largely entered into those improvements necessitating protective works in addition to dredging, they had to be limited in extent and carried on with great caution; and, in view of the small extent of commerce to be benefited, only a few of these rivers warranted any large outlay for their improvement.

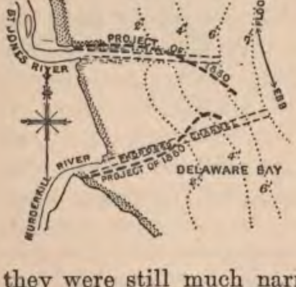
The Christiana River in Delaware, *Fig. 4*, upon which the manufacturing and shipbuilding town of Wilmington was situated, was once a large arm of the Delaware River. Its tidal capacity was gradually much reduced by the reclamation of the adjacent low lands; and it was now a narrow stream about 14 miles long, the low-water widths in the lower section varying between 500 and 800 feet. In its present condition, the stream was able to maintain an average depth in the channel of 12 feet at low tide from the mouth to $3\frac{1}{2}$ miles above. This depth was periodically increased to 15 feet by dredging, the rise of the tide being 6 feet at the mouth and 2 feet at the head of the river. Much material, especially clay, was swept into it during floods and heavy rains from the high uplands to the north and west; and it also formed the receptacle for the drainage and sewerage of Wilmington, and, in consequence, was always charged with sediment. The prin-

Fig. 4.

Mr. Stierle. cipal obstruction to navigation was at the entrance, where a bar existed, which originally had 8½ feet of water over it at low water. This bar, in conjunction with a certain portion of the river above it, had been dredged repeatedly to a depth of 12 feet previous to 1881, when Colonel W. Ludlow constructed a jetty, 1,800 feet long, on the north side of the entrance in a down-river direction to the 18-foot depth in the Delaware River, upon the ebb currents of which its outer end impinged at an angle of 50°. The jetty had deepened the water over the bar about 2 feet; but the channel had moved up against it, and was now very narrow at the outer end. No bar had formed outside the jetty, the configuration of the bottom being the same now as it was before the jetty was built. The contraction of the channel was due merely to an advance under the shelter of the jetty of the foreshore on the south side of the entrance. It had been suggested to partially close the funnel-shaped mouth of the river by another jetty on the south side, parallel to that on the north, leaving an opening of 500 feet at the outer end. General W. F. Smith had presented a design for the erection of a barrier consisting of a series of automatic flood-gates, in the place of a second jetty, which would open during flood-tide, and close during the ebb, thus obstructing as little as possible the influx of the tide, and concentrating the outgoing currents upon the narrow channel at the crest of the bar. The growing shipbuilding interests centring on the Christiana River, had of late years felt the necessity of an increase in the depth of the channel leading to the ship-yards; and a depth of 21 to 24 feet at low water was about to be sought by an extension of the improvement works upon this basis.

The outlets of the Murderkill and Saint Jones Rivers, *Fig. 5*, were about 3,000 feet apart, and emptied into Delaware Bay about 30 miles above Cape Henlopen. The tidal length of both rivers was originally 21 miles; the former, however, was now over 4 miles shorter, many of its long bends having been connected by "cut-offs." The "cut-offs" were made at first from 25 to 30 feet wide, but though some had been widened considerably by the river currents, they were still much narrower than the river proper, which, at the narrowest point, was 90 feet wide. The many counter-currents, the eddies, and the friction thus created seriously inter-

Fig. 5.



fered with the propagation of the tidal wave; and many of the bends of the river that had been cut off were gradually filling up, causing a large reduction in the tidal capacity, the effect of which was particularly felt at the entrance. The river was in a very bad condition; shoals with only 3 feet of water at low tide were of frequent occurrence; and the water at the entrance was so shallow that the bottom was often bare at very low tides. The Saint Jones River, in which considerable dredging had been done during the past ten years, was a more powerful stream. Before its improvement, the rise of the tide was 4·1 feet at the mouth, and 1·2 foot at Dover, 21 miles above; whereas now the average rise was 4·8 feet, and 2·3 feet respectively. At the mouth of the Murderkill River, only recently put upon the list of navigable streams, the average rise of the tide was 3·8 feet, and at the town of Frederica, about 13 miles above, only 1·1 foot; whilst the low-water slope up the river was much broken, and the ebb current almost ceased to run when the flats at the entrance began to uncover, about three hours before low water in the bay. Mr. Stierle.

The original plans of improvement for all the rivers in Delaware were, with one exception, devised between 1879 and 1882; and, as their condition was nearly alike, they comprised expensive works for improving their entrances. Chiefly for economical reasons, the channels inside the rivers were improved first, generally to the nearest town at the head of the navigation; but as these were being gradually completed, the question of improving the outlets across the flat foreshore, nearly a mile wide, ending abruptly in deep water, could no longer be postponed. In 1889 General Smith proposed the experiment of cutting a deep, straight channel across the flats at the mouth of the Saint Jones River, trained on each side by a bank formed with the material dredged from the cut; for the improvements within the river, just completed, were of little use unless the obstructions at the entrance were removed. The commerce of the river hardly warranted the construction of an expensive jetty; and, accordingly, the channel was dredged out at a cost of £1,500, to a sectional area slightly larger than the largest cross-section in the river. A cut, 60 feet wide and 6 feet below mean low water, was made along the axis of the proposed channel, from inside the river to the 6-foot depth in the bay, a distance of 4,800 feet; and along each side a smaller cut was made, 20 feet wide and only 3 feet deep, the berm thus left strengthening the sides of the channel against the weight of the banks. The excavated material, consisting for 500 feet from the shore of black, peaty, marsh mud, further out of sand, gravel,

Mr. Stierle. and boulders, mixed with some blue mud near the outer end, was deposited as far from the edge of the channel as the boom of the dredger could reach. Three years after, the depth along the centre of the channel was still 6 feet and more for 2,000 feet from the shore; the black mudbanks near the shore had settled to high-water level, and the gravel and sandbanks further out were visible only at low water. Beyond 2,600 feet from the shore, the banks, which had been made much lower there than those inshore, on account of the deeper water and corresponding decrease in the quantity of material excavated, had disappeared, and the cuts had been obliterated. Since then no material changes had taken place, and the shoals at the outer end would be dredged to 6 feet, all the depth the present navigation required. A similar channel was now being dredged at the mouth of the Murderkill River, converging towards the channel from the Saint Jones River, and both could be brought together to one outlet, if the growth of the local commerce should justify the construction of more durable protective works along the channels, as proposed in 1881 by Colonel Ludlow.

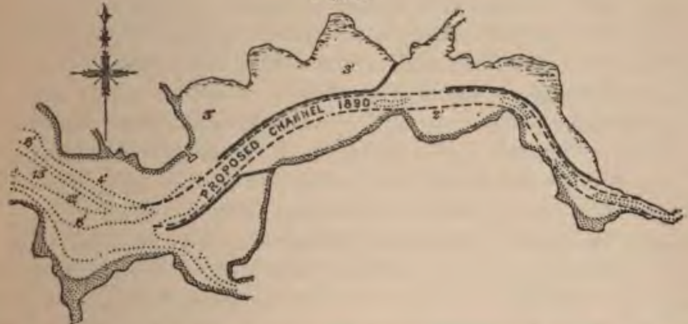
The Mispillion River, *Fig. 6*, entered Delaware Bay 18 miles north of Cape Henlopen, and was 18 miles long; and it had been improved throughout by dredging a channel 40 feet wide and 6 feet deep across existing shoals. Its outlet also was barred by a flat muddy foreshore about a mile wide, and was formerly much further out in the bay, like the outlets of other Delaware rivers, as the shores of the bay were being worn away gradually by the waves. The receding of the shore had brought the coast-line near a bend of the river parallel to it in direction, so that the mouth was bounded to the north by a narrow tongue of marsh, terminated by a long sandy hook with outlying shoals, round which the littoral currents and the waves carried considerable quantities of sand into the mouth of the river. The average rise of the tide was 4 feet. General Smith had proposed trying, in the first instance, to dredge a cut across the flats in a south-easterly direction, 150 feet wide and 6 feet deep at mean low water, protected along the north side by a bank of excavated material deposited by the dredger; but an attempt made a year ago, at the inner end of the cut, proved ineffectual, as the strong set of the

Fig. 6.

tide and waves continually levelled down the banks and swept the Mr. Stierle. excavated material back into the cuts. It was then decided to construct the protective works originally contemplated, consisting of a substantial jetty on the north side, and a dyke of mattresses and clay on the south side, commencing on the north side first, as far out as absolutely necessary; and 500 feet of a pile dyke had already been built.

The Manokin River, *Fig. 7*, was a tributary of Chesapeake Bay; and its estuary, 4 miles wide at the entrance, was 10 miles long, and had a fair depth in the channel, diminishing gradually from 42 to 9 feet, except within the upper 3 miles, where shallow mud-flats, with an average depth of 2·3 feet at low tide, extended from shore to shore. The river proper above the flats was 7 miles long, had a mean depth in the channel of 9·4 feet, and a width varying between 200 and 400 feet. It received only a

Fig. 7.



small quantity of fresh water, principally surface water from the adjoining lowlands. The average rise of tide in the estuary was 2·6 feet. The foot of the tidal wave arrived at the mouth of the river with a velocity of 31 feet per second, crossed the flats with a velocity of only 11 feet per second, and passed up the river with a velocity increased to 19 feet per second. Navigation was carried on by vessels of very light draught, and only during high water, the mud-flats effectually blocking the upper river at low tide. In 1890 General Smith made plans for the improvement of the flats by dredging or otherwise. In order to maintain, or, if possible, increase the present tidal capacity of the river, and in order to allow a free propagation of the tidal wave, it was calculated that a channel across the obstructions would need, at the lower terminus, a sectional area with a mean depth of 13·3 feet and a width of 235 feet, and at the upper limits of the flats, a depth

Mr. Stierle. of 8·9 feet and a width of 150 feet; the intermediary cross-section increasing from above towards the mouth according to the equation of a curve based upon the physical characteristics of the river. This theoretical channel was to be trained along the centre of the estuary, in curves of very large radii, by dykes on the concave sides of the channel raised to low-water level, composed of brush mattresses capped with the stiff blue mud excavated from the channel; but the great cost, estimated at £59,850, compelled an abandonment of the plan. Instead, a channel 100 feet wide and 6 feet deep was being formed, the excavated material being deposited along the edge of the dredged channel to aid in training the currents. As a temporary make-shift, and considering the exposed locality, the improvements made so far were quite a success. The Manokin River was the only river on the Chesapeake side of the district where training-walls were considered absolutely necessary for a permanent improvement of the outlet. The outlets of other rivers requiring a greater navigable depth were simply improved by dredging. The dredged channels gave indications of shoaling only after a lapse of several years, and the required depth could be easily restored at small expense. The material excavated from the channels was taken away upon dumping-scows, and deposited in the indentations of the shore, or in deep water some distance off. One of the best illustrations in Chesapeake Bay of successful open artificial channels having no training-walls, were the extensive improvements made by Colonel W. P. Craighill, at the mouth of Patapsco River, forming the approaches to Baltimore Harbour. Of the many outlets and rivers rectified on the Chesapeake by the above-described method, only two had shown a somewhat greater tendency to shoal, after having been dredged, than others, viz., the entrance to Cambridge Harbour, Md., and the bar at the mouth of Onancock Creek, Va. The deterioration, in both cases, was caused by detritus drifting down the north shore with the prevailing winds; and it might prove necessary to arrest the movement of this material by constructing short spur-dykes or groynes at a certain distance above these outlets.

Mr. Carey. Mr. A. E. CAREY considered that any accurate data as to artificial scour during the latter part of the ebb-tide on a tidal outlet would be of much interest. The system of artificial scour was much more common in French harbours than in those of this country. The danger of applying it was that, while excavating deep holes near the flushing reservoirs, the materials so moved settled again, shoaling the inner edge of the bar. He knew

nces in which its effects were thus detrimental rather than Mr. Carey.
ntageous. In small tidal harbours, where funds were often limited, the use of a harrow on the bar was sometimes a cheap edient for gaining a slightly increased depth, and for preventthe bar from heaping up irregularly.

Ir. EYRIAUD DES VERGNES observed that the best methods for Mr. Eyriaud des Vergnes.
ulating rivers in their fluvial portion appeared not to give rise the present day to any difference of opinion. Mr. Vernonrcourt's Paper explained them very clearly, and confirmed m by interesting examples. Putting aside the proportion t should be maintained between the expenditure and the ults, always a delicate question, their application presented difficulty.

The problem was more complicated in the tidal portion of rivers, ing to the alternate changes in the direction of the current, d a consequent tendency for the ebb and flow to create distinct annels, each passing from one bank to the other. The object be aimed at was to unite these two into a single channel, hich would thus be most efficiently maintained by the alternating rrents. But the modifications of the bed for bringing about this sult should take into account previous works, often undertaken ithout reference to the whole river, should give facilities for the flux of the tide, and should allow for the special conditions due the variations in the fresh-water discharge. It was often fficult to apply with precision the best general rules. He agreed ith Mr. Vernon-Harcourt in considering that dipping dykes suitbly directed were generally preferable to longitudinal trainingalls, for regulating the channel in the tidal portion of a river, nd that the sections should increase progressively seawards; but t appeared to him essential to consider these sections, rather than he actual width of the channel, in regard to these variations, earing in mind that in sections of equal size the resistance to notion increased with the width. He would add that the necessity of a considerable amount of dredging, to produce fixity in the channel, must be admitted, concurrently with the construction of training-walls, if rapid results were desired.

The improvement of the mouth of the Adour was at the present time an object of special solicitude. The historical records of the changes of its outlet indicated that the natural, ancient outlet was near Cape Breton, 10 miles to the north of its present position, and that this was not due to a gradual diversion, since the mouths of all the rivers of that coast were driven southwards under the action of the littoral drift. It was a new outlet, therefore, that was

Mr. Eyriaud des Vergnes. formed in 1578, and not an old outlet that was reopened. The criticism of Mr. Vernon-Harcourt on the original solid jetties, constructed at the close of the last century, appeared to be justified; it would certainly have been more advantageous to have made them converge, by placing them much further apart at their commencement, and carrying them out rapidly to a great depth. Considering, however, the period at which those jetties were constructed, it was not surprising that there had been misconceptions in these works, which had been pushed forward slowly in view of an immediate improvement which could not be maintained. At the present day the problem was better understood, and there were greater facilities now for obtaining large quantities of material than a hundred years ago; but though they would not now do the same as their predecessors, they were obliged to take existing works into account. He did not know from what source the figures indicating the hindrance to the influx of the flood-tide into the Adour had been derived; but it seemed certain that the tide rose as high at Bayonne as outside, and he, therefore, did not think that the flood-tide was checked as much as suggested; but he considered that the causes of its stoppage must be sought rather in the irregularities of the bed of the river above Bayonne. Some regulation works above had already caused the tide to flow 12½ miles further up than formerly, and had consequently increased the tidal volume in the river, which method of improvement would be continued. The narrowing of the outlet was, indeed, mainly produced by the protrusion of the northern beach into the channel, which made the outlet-channel one-third narrower than the jetty channel. Since 1856 an endeavour had been made to direct the ebb current by means of open jetties standing on low rubble mounds, without paying any attention to the advance of the beach into the channel. It was, unfortunately, true that the results obtained were not commensurate with the expenditure; and though the direction of the outlet-channel had been rendered more stable, little increase in the minimum depth has been effected by the works over the bar beyond the jetties. The one definite, though small, advantage gained was that the lowest part of the bar was now in the navigable channel, whereas formerly it was outside this channel.

He considered that the essential defect of the present state of the outlet of the Adour consisted in the openings in the jetties, which allowed the sand to invade the channel, producing not merely projecting shoals inside inconvenient for navigation, but the bar itself as well. The Adour, indeed, brought no alluvium

to the sea, for its waters were clear, and any detritus from inland was arrested from above Bayonne; but the ebb-tide rolled seawards the sand coming in through the jetties, and deposited it very near their extremities, as the force of the ebb was partly lost in spreading right and left through the openings between the cylinders or iron piers. The Adour jetties seawards of the old solid jetties, exhibited four types of open work, namely, masonry viaducts, masonry columns with iron superstructure, iron viaducts with spans of $39\frac{1}{3}$ feet, and, lastly, cast-iron cylinders, $6\frac{1}{2}$ feet in diameter, and $16\frac{1}{2}$ feet apart centre to centre. The two first types partially kept back the beach, as their solid base was raised to the height of low water of neap-tides, and directed the ebb efficiently. The very open iron viaduct, with its rubble base levelled at zero, gave free passage to the waves, currents, and sand; but the portions of the jetties on cylinders were less disadvantageous, for though the rubble base was only raised on the average to $1\frac{1}{3}$ foot below zero, the cylinders left only three-fifths of the length open for the passage of the currents and sand. These open jetties, besides not affording sufficient shelter to vessels passing the jetty channel, gave rise to the principal shoals, one at the end of the masonry columns on the north side, caused by the sand coming in from the top of the beach, forming a projection extending sometimes 230 feet into the channel, and the other outside the jetties, constituting a bar projecting about 820 feet in front of the 5-metre ($16\frac{1}{2}$ feet) line of soundings. The ebb rarely lowered this bar more than 10 feet below zero, and the waves often raised it again to only $6\frac{1}{2}$ feet below this level; so that the depth over the bar at high water was seldom more than $16\frac{1}{2}$ feet at neaps and $20\frac{2}{3}$ feet at springs, which depths were frequently reduced to 13 feet and $17\frac{1}{2}$ feet respectively. Moreover, as the sea broke more violently on the bar in proportion to its height, vessels were obliged to allow for 2 feet of water at least under their keel to avoid chance of accident.

Mr. Eyriaud des Vergnes.

In his opinion the measures to be adopted for improving the condition of the outlet of the Adour should comprise closing the open jetties, to stop all inroad of sand, and to shelter the entrance channel, and also dredging the bar down to at least $16\frac{1}{2}$ feet below zero, which could subsequently be maintained by dredging away the moderate annual volume of material travelling from the north, and tending to come round the northern jetty. This was the aim of the investigations in progress; and as a trial had shown that the sand of the bar was very easily pumped up, a dredger suitably adapted to the local conditions would ensure the

Mr. Eyriaud des Vergnes. maintenance of a depth of 16½ feet below zero in the entrance channel at a moderate annual outlay.

Mr. Evaristo de Churruca. Mr. EVARISTO DE CHURRUCA desired to contribute some particulars of the improvements, effected under his direction, in the River Nervion, and on the bar at the mouth of that river.[1] The town of Bilbao was situated between 8 and 9 miles above the mouth of the River Nervion; and the tide extended about 5 furlongs higher up the river, this part of the Nervion being known as the tidal river, or Ria, of Bilbao. With a width varying from 160 feet in the upper to 525 feet in the lower part of the river, the volume of fresh water was very limited, in dry seasons not exceeding 140 cubic feet per second, or, with some small affluents between Bilbao and the sea, 250 cubic feet. The ordinary volume of river-water flowing to the sea was about 530 cubic feet per second, sometimes increased by floods to as much as 56,500 cubic feet; but these floods lasted for a very short time, so that the navigation of the port was almost entirely dependent on the tidal water. The rise of tide varied from a minimum of 4 feet to a maximum of 15 feet, the mean annual rise being 9 feet; and the volume of sea-water that now entered the harbour at ordinary high tide was about 10½ million cubic yards, which increased to 15⅔ million cubic yards during spring-tides.

The earliest notices in existence of the port of Bilbao concurred in describing its conditions as unsatisfactory. A document dated A.D. 1503 attributed the loss of many vessels every year to the dangerous nature of the bar, owing to its shallowness and instability, and also mentioned that ships were frequently detained in the harbour for long periods, because they could only leave the port at spring-tides, a condition of things which continued until a much more recent period. Early in the sixteenth century the mole at Portugalete was commenced, on the western side of the river mouth, with the object of correcting the tendency which the waters of the Nervion had, in common with all the rivers on the same coast, to bear away westward along the shore as soon as they reached the sea, that being the direction of the prevalent winds. This wall was no doubt also intended to force a passage through the sandbank which formed the bar, but it was not extended sufficiently far out, and before long was partly destroyed by the sea, so that the advantages derived from it lasted only a short time. At a later date, a wall was built on the oppo-

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[1] Minutes of Proceedings Inst. C.E., vols. lxxvi. p. 403; xcviii. p. 431; civ. p. 344; and cvii. p. 458.

site side of the harbour mouth, to control the shifting sands on the right bank, and prevent them from encumbering the channel; but this occasioned a gradual advance of the beach just beyond the wall, which again restored the tendency of the waters of the Nervion to follow the coast-line, and created a sinuous waterway dangerous to navigation. Some works were subsequently executed with the object of narrowing and deepening the navigable channel of the river. An estuary near its mouth, about 1,100 yards in width, and extending inland for nearly 2 miles, was left so nearly dry when the tide receded that only two narrow and tortuous watercourses remained, in which the depth was about 2 feet at low water. Between 1750 and 1760, this part of the harbour was improved by the construction of retaining-walls; but the plan was defective, for, instead of increasing the width of the channel as it approached the sea, the exit from the estuary was narrowed to 137 yards, whereas at the upper extremity it was given a width of 328 yards. While the depth at the narrow part was by this means increased at low tide to 13 feet, and that of the wider portion to 9 feet, the bar, with a constantly-shifting sandbank and only 2 or 3 feet depth of water, remained absolutely unaffected, so that in wintertime, even at high water, the navigation was greatly restricted. Vessels coming for iron ore usually arrived in ballast, drawing very little water, and could consequently enter the river without difficulty; but when laden with cargo, they could only leave the port at spring-tides, and, if the weather was unfavourable, were often obliged to wait for weeks or months before they could venture across the bar. On one occasion, for example, during the winter of 1875–76, although the largest vessels at that time drew only 13 feet of water, they were all detained in the river for three months and a-half. The harbour remained in this condition until the construction of several railways, and the rapidly-increasing importance of the shipments of iron ore, rendered great improvements in the river and on the bar indispensable. Accordingly, in 1878, he presented a report with plans for the improvement of the river, in accordance with which the works had since been executed.

Mr. Evaristo de Churruca.

Besides lowering the bar, the whole of the river required dredging, especially in the upper portion near Bilbao, where a great accumulation of stones and gravel obstructed the navigation; abrupt curves in the channel needed also to be corrected; and the regulation of the river, commenced during the last century, required to be improved and completed. To deepen the water on

Mr. Evaristo de Churruca. the bar was the most difficult part of the undertaking. The insignificant volume of river-water, and the limited extent of surface over which the tidal waters spread themselves within the river, occasioned an unusually sluggish current; and it was expedient to examine very carefully how, under these circumstances, the flow of the tide at the mouth of the river could be most advantageously brought to bear upon the bank of sand and alluvial deposits which formed the bar, in order to create a permanent and deeper channel through it than the then existing shallow, shifting, and tortuous passage. The flow of the rising tide outside the harbour was N.W. to S.E., and its velocity only $1\frac{2}{3}$ foot per second, or about one knot per hour. Part of the incoming water entered the river in a direct line with accelerated motion; but the larger part, striking first against the sandy beach on either side of it, especially on the broad expanse called Las Arenas, on the eastern side, stirred up the loose sand, and, forming separate currents parallel to the beach, carried the sand into the harbour and about 2 miles up the river, until, on the turn of the tide, it was brought back again. The maximum speed of the flood-tide at springs, at the mouth of the river, was only 6 feet per second, or about 4 miles per hour, and if compared with the velocity of the tide entering the River Seine, which was from 12 to 18 miles per hour, was a very moderate current to work with. The flood waters of the River Nervion brought down large quantities of rolling stones, gravel, sand, and mud, which had also to be provided against. The stones and gravel were usually deposited within 2 miles of Bilbao, the finer sand reaching a distance of about 4 miles; while the particles of mud were carried by the water to the mouth of the river, and together with those brought down by the Cadagua river and other minor affluents of the Nervion, generally sank to the bottom on the turn of the rising tide. It did not appear, therefore, that the alluvial river deposits affected the bar; and, moreover, it was ascertained by soundings that this was composed of sea-sand, precisely resembling the sands which formed the beach at Las Arenas and at Portugalete, which consisted, in about equal proportions, of fine silicious grains and pulverized marine shells. He came to the conclusion that the shallowness of the bar was mainly due to the shifting to and fro of the sea-sands by the ebb and flow of the tide, and by the subsidiary currents running parallel to the extensive sandy beach of Las Arenas; and he therefore advised the prolongation of the western mole at Portugalete for 875 yards, extending it beyond the bar to a depth

of 20 feet at low-water spring-tides. The tendency of the ebbing water to flow westward along the shore would thus be corrected, and it would be directed against the bar itself. The mole, if extended in a straight line, would have run due N.W., but by giving it a very slight northerly curve with a radius of 3,280 yards, several advantages were foreseen: (1) The westward tendency of the ebbing current would deepen the new channel close to this sea wall; (2) Without making the passage into the harbour in any way more inconvenient than before, additional protection against the swell of the open sea coming from the N.W. would be afforded to the entrance channel, with advantage to the vessels passing in or out, and an increased depth in the bed of the new channel would be maintained; (3) It was foreseen that the construction of this wall would affect the deposits of sand on the right bank, and probably cause them to advance with it, but the more northerly trend of the wall at the extremity would prevent this sand from settling transversely to the new channel, and it was hoped that it would take a direction parallel to the wall, and thus improve, rather than encumber, the waterway—which was precisely what had happened. A tongue of sandbank had been formed, about 160 yards in length, but its width was so insignificant that in boisterous weather it was frequently carried away by the waves. He, moreover, considered that any prolongation of the existing wall on the side of Las Arenas would probably have the effect of creating a prejudicial reflex action, which decided him to leave the channel open on that side. In the above-mentioned report it was pointed out that in order to complete the security of the port, and to remove all danger to the navigation in tempestuous weather, it would be necessary to protect the outer harbour by breakwaters; but their cost, estimated at £800,000, was far in excess of the funds at the disposal of the Board in 1878.

Mr. Eva de Chur

The works were commenced in 1881, and a due regard to economy, combined with rapidity of execution, determined the mode of construction. It had been ascertained by soundings, to a depth of 26 feet below low water, that no rock foundation could be reached; and the work was, therefore, proceeded with as follows: (1) A pier of wrought-iron upon screw piles was first erected to serve as an auxiliary scaffolding for a foundation of stones up to low-water level, and for a concrete superstructure reaching to high-water mark; (2) the foundation was formed of loose stone thrown into the sea between the piles, and on either side of them, up to the level of low water, and allowed to settle into place before commencing the superstructure. The outer end of this stone bed

Mr. Evaristo de Churruca.

was protected by artificial blocks weighing 27 tons; (3) a solid body of concrete was next constructed on this foundation, reaching a height of 13¾ feet above low-water spring-tides.

The foundation bed was allowed to settle during the winter of 1881–82; and by May, 1882, when it had attained a length of 984 feet and the concrete superstructure 295 feet, the bar had already been so favourably affected that several vessels drawing 17 feet of water were able to issue from the port; and the improvement steadily continued as fast as the work proceeded. Some tempestuous weather in the following October occasione strong currents which increased the depth on the bar from th previous 3 feet at low water to 11 feet; but it also somewh damaged the extremity of the iron pier, which determined tl Board to alter the construction of the then uncompleted 656 fe of wall, and to make the remainder of the pier in a more su stantial manner. The result obtained by the construction of th wall was even better than had been anticipated; for where the report said that the depth on the bar would be increased 11½ feet at low-water spring-tides, it had now attained a depth 14¾ feet; and a permanent fixed channel had been created with width of about 230 feet. At all seasons, vessels drawing 18 fe could now enter at any tide, and even vessels of 22 feet draug during spring-tides. Within the river itself, the abrupt cur which before existed had been removed; the regulation of t river up to the town of Bilbao had been improved and complete and two large basins with good anchorage for ships had be created. The breadth of the channel at the Arenal bridge Bilbao was 197 feet; and it widened gradually until, at 8 mi below, between the moles of Portugalete and Las Arenas, attained a width of 525 feet, with occasionally an increased brea given at points where vessels congregated. The river had b extensively dredged, and had now, throughout its whole lengt minimum depth of 13 feet at low water of spring-tides, so t ships of 3,000 tons, drawing 20 feet, could reach the quay-wall Bilbao. The whole body of water which entered with the t left it again with the ebb, the low-water line being practica level from the sea to the town; while at high water of spri tides, it was 1 foot 7 inches higher at Bilbao that at the mout the river.

The total cost of the works executed in the river and in improvement of the bar, omitting the subsidiary expenditure electric lighting, buoys, cranes, &c., and on maintenance, amounted approximately to £467,590, namely, extension of

jetty, £115,890, and regulation and dredging of the river, £351,700. Mr. Evaristo de Churruca.

In his inaugural address as President of the Institution of Civil Engineers, in November, 1886, Mr. Edward Woods, after describing the mineral railways at Bilbao, and the works of improvement on the bar and in the river, said that "owing to the facilities now given, Bilbao ore, which in 1872 realised 35*s.* per ton, delivered at our ports (one-half the cost representing freights), is at the present time landed at South Wales (where the import is 1,000,000 tons per annum) at a cost of 10*s.* to 10*s.* 6*d.* per ton, including freight, which does not now exceed 4*s.* per ton."[1] This statement justified Mr. Churruca in claiming that at least 7*s.* of the reduction in the freights might be attributed to the works in the river and on the bar. The reduction had been in force for the last eleven years, during which time 48,756,000 tons of imports and exports had been registered, from which it appeared that the advantages derived by commerce during those eleven years from the improved navigation had equalled forty-four times the whole cost of the works. During the years 1878–79, the imports to Bilbao amounted to 144,977 tons, and the exports to 1,195,422 tons, making a total of 1,340,399 tons; whereas during the year 1892–93, the imports amounted to 759,864 tons, and the exports to 4,368,967 tons, or a total of 5,128,831 tons. This notable increase had resulted in a proportionate increase in the funds of the Board of Works, and had enabled them to commence the construction of the breakwater which would enclose and shelter the outer harbour and convert it into an excellent harbour of refuge. The western breakwater, starting at a point about 1 mile from the end of the new Portugalete sea-wall, would be 1,586 yards, and the breakwater on the eastern side of the harbour, 1,173 yards in length. Together, they would completely protect the port from the direct action of the ocean waves, while allowing easy entrance to it for ships. The area enclosed by these breakwaters was 709 acres, of which 507 acres would have a depth of water at low water of spring-tides of between 16½ feet and 50 feet. The estimate of cost of the western breakwater was £890,300, and of the other £344,130, or a total of £1,234,430. The western breakwater was commenced in 1889, and the greater part of its foundation-bed was now completed up to the level of low water. It had already a considerable effect in diminishing the surf on the bar. On the eastern side, the execution of the work was

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 21.

Mr. Evaristo de Churruca. commenced in March of the present year. Both would probably be completed by the year 1900; and Bilbao would then be the finest port in the Bay of Biscay.

Mr. Shoolbred. Mr. J. N. SHOOLBRED wished to make a few remarks on that part of both Papers which referred to the training of tidal rivers. He was well acquainted with the outlets of the Adour and of the Nervion, having surveyed the estuary bay of the latter for the formation of a harbour rather more than thirty years ago on behalf of the late Mr. C. B. Vignoles. He could not agree with Mr. Vernon-Harcourt as to the close analogy which he considered existed in the conditions in which the outlets of the two rivers were placed. The Adour discharged direct into the open Bay of Biscay, and the mouth was exposed to the full force of westerly and north-westerly gales; while the Nervion emptied into a cliff-protected bay, which, though small, sheltered the mouth altogether from westerly gales and also from the full force of many north-westerly ones. The high cliffs on the western or Santurce side, under which a comparatively deep-water channel lay, afforded much more protection than did those on the eastern or Algorta side, where the water was shallower and more exposed to north-westerly gales. The eastern breakwater, not yet made, was, in his opinion, of small importance in comparison to the western one, already constructed. Moreover, he considered that the former should not be in the position indicated on Fig. 17, Plate 2, but further northward, at the projecting point beyond Algorta, so placed as to be outside the western breakwater, and thus protecting the mouth of the harbour from the broken water on the eastern shore. He was glad to note the considerable improvements which had taken place of recent years in the navigable depth of the river itself up to Bilbao—a matter of much importance, not merely to that town, but also to the large trade in iron and coal which was carried on between this country and that part of Spain.

Respecting the distinction which Mr. Partiot drew between the estuaries of the Gironde and the Seine, with both of which he (Mr. Shoolbred) was also acquainted, he could not agree with Mr. Partiot in first classing the former river as having a "narrow-neck" entrance (referring to the contraction between Royan and the Pointe de Grave), and then denying that in the Seine, which he classed as having a "funnel-shaped" entrance, there was any similar narrowing in. Surely the contraction on the Seine between Tancarville and Quillebeuf had quite as marked, and a similar effect, upon the tidal flow in that river, as the one between Royan

and the Pointe de Grave had upon that of the Gironde. He joined with both Mr. Vernon-Harcourt and Mr. Partiot in deploring the large amount of accumulations which had for some years back taken place in the lower part of the tidal portion of the River Seine, and more recently in the outer estuary, especially in the immediate vicinity of the Port of Havre. The accumulations in the estuary during the last fifty years amounted to nearly 500,000,000 cubic yards, and they had caused an abstraction, during spring-tides, of over 250,000,000 cubic yards of tidal water, the largest portion of this damage having occurred during the last twenty years. So seriously, in fact, was the present entrance to the Port of Havre threatened that a proposal had been submitted to, and had been passed by the French legislature, to create a new and more northerly approach to that port by means of an outer harbour, having an area of somewhat over 600 acres, and with a northern and a southern entrance, at a cost of about £3,000,000. The breakwaters would be constructed of large blocks of concrete in two sizes, weighing about 60 tons and 90 tons respectively, built up vertically on inclined beds on a rocky foundation. Much of the success, however, of this attempt to provide a permanent deep-water entrance to the Port of Havre would, it was admitted, depend upon the form which might be given to the extensions through the estuary of the training-walls from Berville to the open sea. Of the many suggestions, the most reasonable (though it did not find favour with Mr. Partiot) seemed to be the "trumpet-mouthed" one, whereby the northern lip of the seaward end would include the approaches to Havre, and its southern edge would rest upon the Ratier shoal, the narrowed neck inland joining, on both sides of the river, the existing termination of the training-walls near Berville. Mr. Shoolbred.

Mr. W. Smith, of Aberdeen, observed that the successful treatment of navigable estuaries for their improvement and conservation was purely practical. At Aberdeen, although the natural tidal basin formerly existing at the mouth of the River Dee could hardly be classed as an estuary, being only 2 miles long by half a mile wide, the low-water course of the river through the basin was diverted southward, in 1869–70, with a view to increase the upland and tidal currents over the bar at the harbour entrance. The whole of the basin was filled up, except an area of 152 acres which was deepened to form docks and tidal harbours. The diversion of the River Dee had no effect, however, as a scouring agency, although the tidal capacity of the harbours and docks exceeded that of the former tidal marsh. Since the River Dee had been diverted, the Mr. Smith.

Mr. Smith. navigation channel, tidal harbour, and docks had been de
by dredging out 6,282,883 tons, of which 3,179,069 tons w
washed in by the sea and rolled down its bed by the River D
3,103,814 tons consisted of boulder clay. The minimum
on the bar, which was formerly 20 feet at high water of
tides, was now 25 feet, the shallowest part of the channel
over a reef of rock about 200 yards within the bar. An im
result of the continued removal of the silt by dredging as
refilled on the site of the bar, by the waves moving th
inward from the bay immediately outside the harbour en
was the deepening of that portion of the bay by wave scour
of the layer of sand formerly overlying the boulder clay to
of 3 to 5 feet, had been swept into the navigation chan
now, instead of a bar of fine sea-sand to be dredged to a d
4 or 5 feet every summer, there were thin patches of san
large boulders on the top. Unfortunately the boulders we
easily swept into the harbour now that they were uncov
the bay than the sand had been. Owing to the friction
extensive surface of the particles of fine sand rubbing up
other under a heavy weight of water, the mass of sand pres
much greater frictional resistance to movement along the
by waves than large stones. The sand brought down by th
Dee was rolled into a deep basin in the inner part of the
tion channel, from whence it was easily lifted by the dred
sent out to sea in hoppers. The direction further impr
must now take at Aberdeen harbour was deepening the
by rock-cutting and dredging, and protecting it from the
of boulders and silt by additional sea-works.

The greatest action of waves upon the sea-bottom at A
appeared to occur in depths of between 2 and 6 fathom
action was consolidated by the influence of the depth, or
water, upon the water at the bottom, the difference of hea
the height of the wave being transmitted most favourably
depths. Wave scour on the sea-bottom occurred, however,
greater depths than 6 fathoms, depending upon the heigh
waves. As the depths shoaled below 2 fathoms, the powe
waves was dissipated in churning as breakers, the head
sure at 2 fathoms or more being required to keep th
unbroken. In the expression he had formerly given[1]
scouring power of a wave, $p = q\left(wd + w\,\frac{v^2}{2g}\right)6a^2$, where q

[1] Minutes of Proceedings Inst. C.E., vol. c. p. 202.

viscosity, w the unit weight of water, d the depth from crest to trough, and a the length of side of sand or stone cube, q might be regarded as the coefficient of the action of the unbroken wave upon the materials of the bottom, the remaining proportion of the power of the wave being spent on continuing the movement of the wave to the shore, and in cresting and breakers. Thus the continuance of the movement of a wave over a shoal, at a uniform depth just sufficient to keep the wave from cresting or breaking, would result in the whole of the power of the wave being spent on the movement of the materials of the bottom. The principal banks in the great estuaries of the British Coast might have been formed while the mean level of the sea was higher by about 12 feet all over Western Europe, which historically would probably be prior to the time when the Roman harbour of Ostia fell into decay 1,300 years ago. The retirement of the sea from the land through the variation of glaciation at the poles, as demonstrated by Adhemar and Croll, would thus account for the present cessation of natural forces in the movement of banks and estuaries. The formation of the Mississippi delta from the average yearly amount of alluvium stated, 300 million cubic yards, must have occupied a period of 355,000 years under the most favourable circumstances, that is, while the greater part of the area was still submerged. Mr. Smith.

Mr. L. Franzius remarked, in reference to Mr. Vernon-Harcourt's statement as to the increase of the tidal volume passing Bremerhaven, that the actual volume had, up to the present time, shown very little variation, and that the theoretical increment quoted would require corresponding modification. On the other hand, the volume at Farge (about half-way between Bremen and Bremerhaven) had increased from 514 cubic yards to 810 cubic yards per second. The tonnage and draught of vessels arriving at Bremen had considerably increased since the execution of the training-works[1]. During the year 1893 the number of sea-going vessels traversing the Weser as far as Bremen was thirteen hundred and seventeen; of these, four hundred and eleven had a draught exceeding 14 feet, eighty-five more than 15½ feet, and fourteen between 16 feet and 18½ feet. During the month of April, 1894, the number of vessels drawing more than 13 feet was forty-two, two of these having a draught of 16½ feet. Mr. Franzius.

[1] Mr. Franzius has presented to the Library of the Institution, Part ii. of "Fortschritte der Ingenieurwissenschaften," Group 2, containing (pp. 48 to 60) an account of the training-works carried out on the Weser, and the harbour works at Bremen and Bremerhaven (pp. 62 to 73).

Mr. Wells. Mr. L. B. WELLS observed that few questions had given rise to so much controversy among engineers of late as the training of estuaries, and there was no subject at the present time better deserving the attention of the members of the Institution. In a Board of Trade return of 1890, it was shown that whereas in 1840 the tonnage of vessels entered and cleared from ports in the United Kingdom was 9,439,667 tons, in 1889 this tonnage reached 71,889,895 tons, an increase of nearly 800 per cent. in fifty years. As the numbers given referred to register tons, and the tonnage of steamers, which carried much more on their register than sailing vessels, had increased from 791,555 tons to 58,764,200 tons in that period, the bulk of cargo handled was much greater than the figures of 1889 denoted. The increase in the size of vessels demanded deep water and improved channels; and it was necessary to provide accommodation to meet the present requirements and further expansion of this enormous traffic: to supply this ports and estuaries must be improved. Much had been done during the latter half of the century, since the Tidal Harbours Commissioners reported; but he considered that much more would have been accomplished for the improvement of estuaries by training-walls had the Commissioners worded their report more circumspectly. They condemned in unqualified terms all reclamation, because the tidal area would be reduced; and a reduction of tidal area was held to be necessarily followed by damage to the navigable channel. Training usually caused accretion, at any rate in some portion of an estuary; and very frequently harbours existed on the lower portion, with monetary interests antagonistic to the development of ports higher up, and this dictum of the Commissioners had been often used with effect to prevent any works being undertaken for the improvement of estuaries. Where the chief authority and population were situated away from the sea, estuaries were improved by training and dredging, as the Clyde, the Tyne, and the Tees, which had resulted in enormous benefits to the communities. By training a channel a maximum service was obtained from the momentum of the water passing in and out of it, which momentum was necessarily lessened when sandbanks were being moved and new channels formed. The dock and river-walls on both sides of the Mersey at Liverpool had stereotyped a channel for a considerable distance, and the effect was felt far beyond the limits of the walls, and had rendered the lie of the channel, both northwards in the direction of the bar, and southwards in the direction of the Upper Mersey, much more stable. In the upper estuary this had been followed by a gradual improvement in the

navigable depth, as evidenced by the larger vessels trading to the Upper Mersey ports from decade to decade. For a distance of about 4 miles, the outer embankment of the Manchester Ship-Canal was almost wholly in the estuary, from just above Runcorn to below the Weaver mouth, and, like the walls on the Liverpool and Birkenhead sides of the Mersey, had cut off certain baylets into which the tide used to flow and the main channel frequently wandered. Since the completion of this embankment, the direction of the channel opposite Runcorn had altered but little; a sufficient time, however, had not yet elapsed to test the permanent effect. Information in his possession showed that the low-water level had been lowered at Runcorn bridge, and had never previously been known to fall so low at Weston Point as it had done this year; this was the best evidence of an improvement in the navigable depth. The increase in the low-water section at the bar, which was now being dredged so successfully by the Mersey Dock Board, had probably helped to effect this; but, in his opinion, the modified training had materially assisted in improving the channel. It was noticeable that the improvement had taken place during a period when the rivers had been unusually free from heavy land floods, and when there was a newly-made outlet for the Mersey water at Eastham, and any change was, therefore, attributable to tidal action. In times gone by, and also in recent years, marshes and foreshores had been reclaimed, and the tide excluded over large areas of the Mersey estuary. During the construction of the Manchester Ship-Canal, and since its completion, large volumes of tidal water had been displaced; and since, notwithstanding this, the channel had improved, it was fair to assume that these alterations were beneficial. Mr. Wells.

Careful records of works carried out in estuaries and their effect on the channels, bar, and tides, were much to be desired. The late Captain Calver, R.N., surveyed many of the harbours and estuaries on the coasts of England, both before and after training-works had been commenced, and gave the results of his experience in his book on Tidal Rivers, which engineers connected with estuary works might study with advantage.

Mr. BINDON B. STONEY observed that he was frequently struck with the manner in which the past generation of engineers, when engaged in training rivers, somewhat slavishly followed the curves which nature delighted in, in place of boldly making long straight reaches, even at the expense of apparently opposing nature, but really by controlling her. Their idea, and it seemed to prevail still to a certain degree, was apparently that long sweeping Mr. Stoney.

Mr. Stoney. curves were more easily maintained than straight reaches; and some of the rivers described in the Papers illustrated this tendency. In the case of the River Moy, in the west of Ireland, he had succeeded in forming a trained navigable channel which, when the works were completed, would extend in one straight line for a length of nearly 5 miles—from Ballina quay to a short distance inside the bar. The natural channel of the Moy at low water was very tortuous, and apt to shift from side to side of the river and estuary, with frequent shoals that greatly impeded navigation; but the improved portions of the channel were now straight, and had from 3 to 4 feet greater depth than formerly. This was due to the current being confined within nearly parallel walls, but which gradually diverged as they approached the mouth of the river, and which extended to a little over half-tide level. The revenue of the Moy Commissioners did not admit of expenditure on dredging; and the principal cutting action took place when the ebb-tide was augmented by a river-flood from heavy rains. In other river improvements that he had been connected with, the navigation channel had been permanently injured by the original designers stereotyping the curves and bends of the natural channel.

Though the special conditions of every river necessarily required special treatment, yet a few general principles might be laid down which would seldom require much alteration. (1) Bends should be avoided whenever practicable, and nature's tendency to curve or meander from side to side of the river-bed controlled, sometimes even at the risk of not immediately gaining quite as deep a channel as nature had already provided in the curves. (2) Operations should be commenced from the higher end of any one series of improvements, for each modification of a river channel, though it might perhaps have little or no appreciable effect on portions higher up, almost invariably had far-reaching effects on the river lower down; and the influence of such improvements on the lower reaches should, whenever practicable, be allowed time to develop, and their consequences should be carefully studied before commencing operations farther down. (3) Training-walls in tidal rivers and in tidal estuaries should be made no higher than was absolutely necessary, lest serious silting should take place behind them, and the tidal capacity of the river or estuary be reduced to such an extent as injuriously to diminish the scour lower down or on the bar. Where funds admitted of dredging on a large scale, the height of training-walls might often be greatly reduced, and, in fact, either omitted as in the Liffey outlet, or only made just high enough to define the navigable

channel and prevent it wandering from its proper direction. If this course had been adopted in the estuary above Liverpool, and if the Manchester Ship-Canal had been brought through the Runcorn sands by means of a dredged channel bordered by low stone-protected slopes, this stone fencing possibly not reaching as high as low water, there would doubtless have resulted a great enlargement of the tidal capacity of the estuary, by the lowering of the sands for wide distances on either side of the excavated channel, as the sands would, under the influence of frets, tidal currents, waves, wind, and wash of passing steamers, gravitate into the deeper channel, to be thence removed by dredging or by sand-pumps, now so successfully employed by Mr. Lyster on the Mersey bar. The width between the training-walls of rivers, when funds were not available for dredging, and when, therefore, the improvement and maintenance of the navigable channel depended on scour, required very careful consideration, as the channel must be wide enough for safe navigation, and at the same time the walls must be close enough together to give sufficient velocity to cut away shoals when there were freshets in the river, and at other times to maintain the normal depth. Probably $2\frac{1}{2}$ to $3\frac{1}{2}$ miles an hour was the least velocity that would appreciably cut away sandbanks. In tidal rivers and estuaries, and when the land water was of small account, the maximum cutting effect of ebb-tides was confined to spring-tides, and generally occurred about the third quarter of ebb, as the current was then, for the most part, confined within the borders of the trained channel, and the volume of water was still large, and its velocity at its maximum on account of the gradient of the falling tide having its steepest slope at about half-ebb. In the last quarter of ebb, not only was the velocity much reduced, but the volume of moving water was diminished; and this materially affected its capacity for carrying sand. Mr. Stee

The Authors of the two Papers differed widely in their views of the best mode of improving the Seine estuary. Mr. Vernon-Harcourt advocated a trumpet-shaped outlet, while Mr. Partiot proposed restricting its outlet to a narrow neck. The latter method had in some cases been most useful for deepening bars and protecting the estuary inside from wave-action; but the recent successful application of sand-pumps to the improvement of the Mersey bar seemed to indicate a possible new departure in the treatment of sandy estuaries and outer bars.

Mr. C. P. Fowler stated that the Burry inlet, fronting the seaward portion of the River Loughor in South Wales, was some- Mr. C. P. Fowler.

Mr. C. P. Fowler. the line of deepest water was consequently so circuitous that vessels were unable to follow it. He concluded that training a channel through an estuary by means of one wall would not produce satisfactory results. He had suggested an alternative scheme, consisting of two walls, the northern one of which would prevent the water from the reservoirs encroaching too far into the north shore; the point of confluence of the two low-water channels would be nearer the harbour; and the channel would be led into a more central course through the estuary.

A comparison of old and recent surveys of the Burry Inlet, *Figs. 8* and *9*, showed that the low-water channel had completely left Penclawdd, and from Llanelly to Burry Port was much nearer the north shore; whilst the deep pool at Burry Port had extended further east, and the available depth into the harbour was about 6 inches less. From Burry Port to sea, the south channel appeared to be filling up, judging from the diminution in the area of the 2-fathom line; but the north and central channels had remained fairly stationary. The sandbanks were much lower; and the seaward 2-fathom line had advanced about a mile in an easterly direction, towards the harbour.

The case of Llanelly afforded an instance of the inability to adopt a hard and fast rule for the treatment of an estuary; the natural configuration and the side upon which the chief industrial towns happened to be situated affected the question very materially. From experience on the Tees and Ribble he had derived the following impressions: However accurate the theory of training-walls slightly diverging towards the sea might be, there would be a tendency for the flood-tide ascending such a channel to become concentrated, and to attain an increasing velocity as it ascended, resulting consequently in a " boil " in shallow channels, and a tendency to force sand into the upper reaches; and unless the channel received tributaries on its way to sea, the velocity of the ebb current would become more sluggish through expanding in the lower reaches, and lead to deposits. He had observed the flood-tide at springs ascending the Ribble; and after the training-walls, which were about 10 feet above low-water level, had been covered, the tidal water ran up the trained channel with a perceptible elevation of 1 foot above the general level of the water at the back of the walls, and at a velocity of about 6 knots an hour. The velocity of a current was either subject to the head of the tidal wave, or the inclination of the bed of the channel; and it therefore appeared that the width of a channel should not be unduly restricted, so as to necessitate an abnormal velocity at any

rticular point, necessary to fill the receiver above that point; Mr. C. P. Fowler.
d in order to prevent accretion, the width of channel at any articular point should have some definite proportion to the duration of the flood, either present or anticipated, consistent with a ormal velocity at that point. It would be better to provide for n increase in tidal volume than risk excluding or checking the ropagation of the flood-tide by endeavouring to arrive too near theoretical capacity of channel.

Bars, bends, and sandbanks tended to keep up the level of low-water in the upper reaches; and by cutting through two bends on the Tees the low-water level at Stockton was considerably lowered. Curves therefore, which might be termed horizontal bars, should be avoided in any scheme of river improvement. The dredging away some clay bars on the Ribble, between 4 and 6 miles below the dock entrance, resulted in the lowering of the low-water level at the dock about 6 feet. By observing the level of these bars, it should be possible to ascertain the length of training-walls required to obtain a certain depth at a particular point above, as there must be an inclination per mile in the bed of a river which was normal; and after this had been attained, dredging must be resorted to. It was probably a mistake to train a channel too near one particular shore, with the expectation that the hard mainland would obviate the necessity of two training-walls. The depth of a trained channel in a sandy estuary was dependent, to a great extent, upon maintaining the top of the wall at a uniform level; whereas, by trusting to the mainland to act as a training-wall, no regularity of contour could be depended upon, and irregularity of contour led to distortion of currents and the formation of banks.

As training-walls were intended to train the last of the ebb and the first of the flood, so that the trained channel was consequently the deepest, it would appear to be incurring unnecessary expenditure to construct them to half-tide level, thereby inducing accretion, and prejudicing the stability of the wall if accretion did not take place. The training-walls on the Ribble had not proved so successful as was anticipated, probably in consequence of the channel being trained of necessity too far to the north of the estuary, as the inhabitants feared that if the river was trained more through the centre of the estuary the piers at Lytham and St. Anne's would be affected. The flood-tide and prevailing winds from the westward had, in consequence, the whole of the estuary to the south of the training-walls to work upon; and there was a tendency for the sand to be forced up in wedge fashion to the upper part of the estuary, and to drop into the channel. The

Mr. C. P. Fowler. prevailing winds and gales in expansive estuaries like the Tees, the Ribble, and the Burry Inlet, were probably as important causes of alteration in the banks and channels as the currents themselves; and when possible it would be better to train channels in the direction of the prevalent winds rather than transversely to them, so that wind-driven sands might drift in the direction of the channel rather than across it.

The width between training-walls and the rate of their divergence were probably of greater import in rivers with a high range of tide and a rapid inclination of bed, than in rivers with an average range of 15 feet. The number of rivers on the west coast, the deepest inlet channels of which pointed in a direction opposed to that of the tidal wave of the ocean, seemed to favour the supposition that the inlets were more subservient to the flood than the ebb. The south breakwater on the Tees was considered to have prevented the beach drifting across the outlet; and the bar was gradually lowered by the scour concentrated thereon by the training-walls.

Mr. Bourdelles. Mr. O. BOURDELLES observed that, whilst rendering due respect to the science and learning of these distinguished engineers, he considered that there was an important omission in their Papers in respect of the study of the laws of the tidal currents in rivers or estuaries, and the influence of these currents on the designs of improvement works. This question was, however, one of the most important for such designs, since the currents shaped the channel and their scour provided the requisite depths, or at any rate their normal maintenance. Nevertheless, engineers had hitherto almost entirely confined themselves to obtaining the velocity of the current at the surface by some cursory observations, or to the calculation of their mean velocity by approximate methods; and relying on these data, had, without any proof, extended the laws of the flow of water in rivers to tidal currents. This wholly unscientific method was liable to lead to serious errors and most unfortunate results. As an instance, he would describe the results he had arrived at when he had to draw out a scheme for improving the estuary of Lorient.

Previously to the preparation of this scheme, innumerable observations had been made during several years of the velocities in various suitable sections of this estuary; and at stations 65 feet apart, in each of these sections, the rates of flow and the directions of the currents were noted at five different depths, namely, near the bottom and near the surface, at mid-depth, and at two intermediate depths. These observations were carried on un

interruptedly during the whole day, at intervals of only a few minutes, so as to give the distribution of velocities in the same vertical at all times of the tide; and they were continued at the same station throughout half a lunation at least, so as to determine the influences of neaps and springs. The observations were repeated as often as necessary for the purpose of verification, and especially during the floods of the two rivers which formed the roadstead of Lorient. Brüning's tachometer was employed for measuring the velocities; it consisted of a disk of the density of water, kept perpendicularly to the current, and connected by a thread passing through the groove of a pulley to a steel-yard placed, out of the water, on a raft which carried the whole apparatus; and the graduated dial of the steel-yard indicated the pressure of the water against the disk. By this very simple contrivance the whole vertical of a station could be easily and rapidly observed, for which purpose the raft was provided with a metal cable anchored vertically on the bottom by a heavy weight. The pulley of the tachometer carried a socket, suitably weighted, attached to the cable; and a marked line enabled the apparatus to be raised or lowered to the desired position. A rudder, placed at the same height, indicated the direction of the current, by means of a wooden rod raised just out of the water, and terminated by a pointer turning on a fixed base. This expeditious process enabled the observations to be multiplied to such an extent as to indicate the phenomena most clearly; and therefore he was in a position to state the precise laws of the rate and direction of the currents, under all conditions of the tide, at the approaches of Lorient. Mr. Bourdelles.

The flood current always commenced near the bottom, and gradually extended its influence upward to the surface, in a period which varied considerably according to circumstances. Where the channel was very narrow, a few minutes sufficed for the flood current to reach right up to the surface; whilst at other places, not less than half an hour to three quarters was required at spring-tides, and often over an hour and a half at neaps. The maximum velocity of the flood current was near the bottom at the beginning of the rise of tide, and remained in the lower part of the water up to half-tide; but from this period it rapidly approached the surface, and continued near the surface till high water. The ebb current conformed to the same laws, for it began at the bottom, and extended gradually upwards to the full height of the water. The maximum velocity, moreover, of the ebb was found at first near the bottom, remaining in the lower portion of the stream till half-tide; and then it rose rapidly

Mr. Bourdelles. towards the surface, near which it continued till low water. The period which the ebb current occupied in spreading from the bottom right up to the top varied according to circumstances, and under the same conditions as given for the flood-tide. During land floods, however, sufficiently large to make the fresh water predominate at the surface, the ebb current extended nearly simultaneously from bottom to top, just as if the channel was very narrow. Strong winds, also from the sea, and the very high tides which resulted, had a disturbing influence; but except under these unusual conditions, the above rules were always verified.

Generally there was no slack water in the mass of water, for the flood or ebb currents commenced at the bottom, when the contrary currents of the tide coming to a close, were still flowing at the surface. Accordingly, on the same vertical, a current and a counter-current co-existed, till the bottom current, spreading gradually to the top, stopped the surface current; and these counter-currents lasted, with varying velocities, for periods which might reach three-quarters of an hour at springs, and an hour and a half at neaps. The period of their co-existence varied in inverse ratio to the tidal coefficient, the section of the channel, the fresh-water discharge, and the force of the wind, or in a contrary sense to the causes which increased the rate of flow of the waters.

The distribution of the tidal currents, manifested by the experiments made at the approaches to Lorient, could not be an isolated phenomenon, but was clearly a local indication of a general law which sufficiently varied observations would doubtless eventually establish. Already a number of facts had been ascertained confirming this law, especially in relation to the beginning of the flood-tide, many very convincing examples being quoted in "The Pilot of the West Coasts of France,"[1] and in the nautical directions published by the French hydrographical department, particularly in those relating to the Congo. Accordingly, though the phenomenon had not yet been studied in detail, like at Lorient, it was nevertheless known to most sailors. Although the action of the ebb current had not been so clearly established by ordinary observations, it was not less proved by uncontested facts; and it was to its action on the bottom at the commencement of the fall of the tide, that the depths, often considerable, found in tidal rivers must be attributed, and which could not be accounted for by the

[1] "Le Pilote des Côtes Ouest de France," 1873, vol. i. p. 336, and vol. ii. pp. 197, 294, &c.

ordinary flow of water in rivers. Thus at Lorient, where the surface currents did not exceed 4 knots, depths of 105 feet at low water of equinoctial springs were met with; and at the mouth of the Congo the depths exceeded 1,200 feet. The distribution of the currents of flood and ebb might, moreover, be explained in a plausible manner as being a consequence of the action of the tidal wave, on the condition of regarding it as a wave of oscillation, and not of translation as was more often wrongly done. Mr. Bourdelles.

Though the subject admitted of further development, he thought that he had proved that a detailed investigation of the distribution of the currents at the different states of the tide should, in each special case, precede the design of schemes for the improvement of rivers and estuaries. Such an investigation would have the advantage of manifesting the use that might be made of the bottom currents at the beginning of the rise and fall of the tide. It would probably show that, owing to the action of these currents, the best way, in most cases, of improving rivers consisted in forming as deep a channel as possible by dredging, whose section below mean low water could be easily determined by practical considerations, and whose maintenance could be effected by low training-walls raised to about the level of low water of neap-tides.

Mr. A. F. Fowler.

Mr. A. F. FOWLER observed, with reference to Mr. Vernon-Harcourt's remarks as to the assistance given to the designing of river works by the use of models, that, while admitting the interesting nature of such experiments, he considered that the excessive relative weight of the particles acted upon by the current available in the models, compared with the current under ordinary conditions; and the absence of wind-action in any way approximating to nature, made the results obtained from the experiments of no value for practical purposes. Mr. Vernon-Harcourt and Mr. Partiot both referred to the action of prevalent winds in affecting the outlets of rivers; but the precise action of the wind was dealt with very briefly and incompletely, and as described was not in accordance with his experience. When the direction of the prevalent wind directly faced the outlet of a river which was environed by exposed sandbanks, the sand was drifted in a direction parallel with the stream; and where the area of exposed sand bore a large proportion to the area of the channel, this parallel drifting was a matter of the greatest importance. The estuary of the Ribble extended over some 45 square miles, of which about two square miles were low-water channel, and 40 square miles were sandbanks exposed for four hours every tide.

Mr. A. F. Fowler. The estuary was entirely open to the prevailing south-westerly winds; and even during moderate gales, the clouds of drifting sand on the 10 miles of north foreshore between Warton and Southshore were so dense as to make it almost impossible to walk against the wind. Anyone who had seen the drift sand on this estuary during equinoctial gales, must be impressed with a sense of the great difficulty which would be met with in maintaining any channel across its direction. His experience had led him to the conclusion that in such cases the action of the wind upon the current was of secondary importance to its action upon exposed sandbanks.

Mr. Fleury Mr. J. Fleury remarked, with regard to the improvement of the outlets of tideless rivers, that the great success achieved by Sir Charles Hartley at the Danube justified Mr. Vernon-Harcourt's conclusions in giving the preference to jetties over dredging; but, in his opinion, this definite conclusion should not be regarded as a general law applicable to every case. He would remind Mr. Vernon-Harcourt of the discussion on this subject at the Naviga tion Congress at Paris in 1892, and the first resolution of the Fourt Section of the Congress,[1] recommending the trial of dredging i the first instance, before resorting to the execution of defini works, the results of which were never absolutely certain. Withi recent years the operations of dredging had been greatly perfecte so that it was now possible to remove large quantities of alluviun from estuaries at very low prices. In several instances it migh be quite as economical, and even more so, to expend upon dredging a sum equal to the interest and repayment of the capital require for the construction of jetties. Moreover, with dredging, ther was the further advantage of being able to modify its action o the currents, in accordance with the new conditions which migh arise, and not to pledge the future. These considerations applie equally to the estuaries of tidal rivers; and the improvement i depth obtained over the Mersey bar by dredging alone was a encouragement to those who desired that the same method shoul be tried at the Seine outlet, between Berville and the Amfard deep

With reference specially to the improvement of the Sein estuary, which was still the subject of numerous discussions in hi country, and upon which a definite solution was far from havin been reached, Mr. Vernon-Harcourt's Paper contained some ver significant information. All the schemes of jetties and training

[1] V^me Congrès International de Navigation Intérieure, Paris, 1892, Procès Verbaux des Séances des Sections, pp. 650–656.

walls described by Mr. Vernon-Harcourt had strenuous supporters amongst French engineers; and the only point on which they agreed was, that under no consideration should the tidal water entering the estuary be reduced in volume. The results obtained by Mr. Vernon-Harcourt, in his ingenious small-scale models, furnished a convincing proof of this. Mr. Partiot, in his present Paper, acknowledged this, and yet he again brought forward his oft-proposed scheme of a transverse breakwater, Fig. 4, Plate 4, whose only effect would be to cause accretions which would greatly reduce the capacity of the estuary, and in a short time compromise the existence of any channel. Mr. Partiot's ideas were far from receiving the support of most French engineers. He (Mr. Fleury), whenever opportunity offered, insisted upon these two considerations: (1) That there was in every scheme for training an estuary, a coefficient of probability, which often reached the limit of an absolute uncertainty as to the results; and (2) that dredging operations, actively carried out as on the Mersey bar, would produce an immediate effect which could be easily maintained, and that, as the cost of dredging was being constantly reduced, there was every advantage in trying this method before any other. Mr. Fleury.

Mr. R. Le Brun considered that the investigations for the improvement of rivers and estuaries would be remarkably facilitated if the influences the great maritime phenomena exercised upon each other were better understood, such as the transport of sediment by the water, and the action of winds, currents, and waves upon the coasts and the bottom. Numerous works had already afforded appreciable results, practical rules had been laid down, and laws indicated. Experiments also tried with small-scale models had yielded some valuable information; but they were only at the beginning of their investigations, and he desired specially to draw the attention of engineers to the reciprocal action of currents on each other. The action of a continuous current on a river with a shifting bed, and the influence of the curvature of the banks on the position and depth of the channel, had been investigated; but to complete the inquiry into the laws of rivers, it was expedient to examine the effect of a large tributary, which might produce extensive perturbations in the main river both above and below its confluence. Thus, assuming that a tributary CD, *Fig. 10*, joined the main river AB nearly at right angles, this secondary current would check the main current; and the loss of velocity would result in a rise of the water-level above the confluent, leading to floods and the formation of shoals. The molecules passing in the direction MN would be diverted at N in Mr. Le Brun

Mr. Le Brun. the direction of the resultant of the two velocities toward bank at P; and if the bank was firm, they would be towards Q, or the bank would be eroded if soft. Large w been carried out to regulate the confluence of some larg badly directed by Nature, so as to mitigate the disaster periodically resulted. If the lines of the banks and the of the streams were under control, it would be advisable to them so that the current of the tributary might assist in the main current suitably and deepen the channel. In a

Fig. 10.

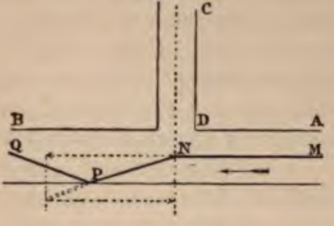
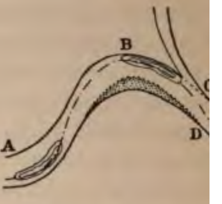


Fig. 11.



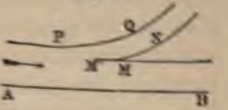
river, A B C D, *Fig. 11*, suitably regulated, the deep plac be found in the concave bends, a little down-stream of th of the bends; and the channel hugging the concave ban across from one bank to the other at the change of curva followed that the best position for the mouth of the would be at the point of inflexion C, just below the conca so that the secondary current would tend to direct t current towards the next bend, the deep hollow abo prevent the formation of the shoal which was generally above the confluence, and would scour the shoal whic to form at the point of inflexion between C and D. special cases, when the tributary was not navigable and could be raised without inconvenience, it might be mad over in a thin sheet on the concave bank, so that its wate join the main current without any appreciable transverse thus augmenting the volume of the stream without modi direction. The fall of the waters of the tributary on th bank, where accretion took place, would put the sedim suspension and occasion its transport into the deep hol would disturb the state of the river; but this action useful if it was desired to remove the deposits at this ban

Considering next the inverse case of a river branchin two channels at a point M, *Fig. 12*, the proportion of through each channel could only be determined by the

the channel, and the fall, direction, and nature of the current, according as it was due to ordinary flow or to tidal propagation. The distribution of the flow, however, could be greatly modified by a spur M′M from the point, whose length and direction exercised a most important influence on the discharges; and by this means it had been possible, at the bend of the Rhone delta and at the Bec d'Ambès on the Gironde, to give each channel its suitable discharge. The direction should be adjusted so that the flow should be free from eddies, which would impede the discharge, diminish the velocity of the current, and produce silting up above the point of separation in the channels themselves. Great care should be taken to give such a direction to the bank A B that the current might not be driven into the less important branch; and the spur should be placed so as partially to shut off the branch P Q, and to facilitate the admission of the current into the main channel; and dykes should be constructed if the banks were not firm enough or high enough to prevent the two currents from falling into each other, and along a sufficient distance to secure the direction of the current. These works should be so designed in tidal rivers as not to impede the ebb currents, and to give them as much as possible the same direction as the flood-tide, of which the works at the Bec d'Ambès furnished a most interesting example. The study of these phenomena had a much greater and more general importance than those simple ones previously examined; they were found above and below the numerous islands scattered over some rivers; and their effects were seen in the bed of rivers in which the width was very large in proportion to the depth, and the form of whose banks had little influence to maintain the direction of the currents flowing in various directions under the very different actions of the flood and ebb in the tidal portion. They were specially found in estuaries at the meeting of the flood and ebb currents, running in various directions in the secondary channels, and in the blind channels between the banks. These phenomena were more obscure and more thoroughly altered when the currents flowed through masses of waters of variable depth, and of varying density according to the saltness and the materials in suspension; but a precise knowledge of the effects of the meeting of two definite currents should throw a great light on the probable results of these more complex conjunctions. Examples should be sought in estuaries well sheltered from the wind by high hills, and separated from the sea by a narrow neck which fixed the direction of the flood and ebb

Mr. Le B

Fig. 12.



Mr. Le Brun. and preserved the estuary inside from disturbance by storms. Under such conditions, the movements of the mass of water would preserve a certain permanence which would enable the effects of the currents to be better distinguished.

The Foyle estuary, which was enclosed by Macgilligan Point, Fig. 15, Plate 4, and into which the river flowed at the head of the estuary through a narrow channel at Culmore Point, above which the flood-tide accumulated large volumes of water, combined the best natural conditions for this investigation; whilst its bed, composed of sand and silt, was essentially movable. The principal channel exhibited a remarkable average regularity, following the great concave bend of the northern shore, under shelter of the Donegal mountains; and the sandbanks rose from the channel with a very gentle slope to the south shore. These banks were intersected by blind channels, serving for the admission of the flood-tide and also for the outflow of the waters covering the bay at the commencement of the ebb. All these blind channels opened into the main channel, and having a sharp slope seawards gave rise to transverse currents in the principal channel. Above the confluence of each of these blind channels, shoals had formed in the main channel; and below their confluence there were deep hollows. The main depth of the principal channel increased from the head of the estuary down to the neck, where it attained a maximum; and a bar had formed beyond the neck, as well as Tans bank outside the channel, and separated from the coast by a well-defined hollow. The moderate changes in depth, noticeable in the main channel, seemed due to irregularities in the shore, such as Quigley Point, and the secondary current to the west of the Great Bank had driven the channel against the shore a little above Moville. If these results were compared with those observed at the meeting of two ordinary currents, the same effects would be noticed, namely, the secondary current pushing the main current against the opposite bank, and the formation of a hollow below, and a shoal above the confluence. In the estuary of the Foyle the ebb current appeared to preponderate, as in the bay of the Seine. There was here too close a concordance for it not to be attributed to cause and effect; and he believed that he had been able to notice similar phenomena, even in the Seine estuary, though the great and frequent changes there prevented equally characteristic effects being noted.

He had endeavoured to apply these ideas to the improvement of the Seine in 1888, when he studied the question in conjunction with Mr. de Coene. Mr. Vernon-Harcourt had submitted their

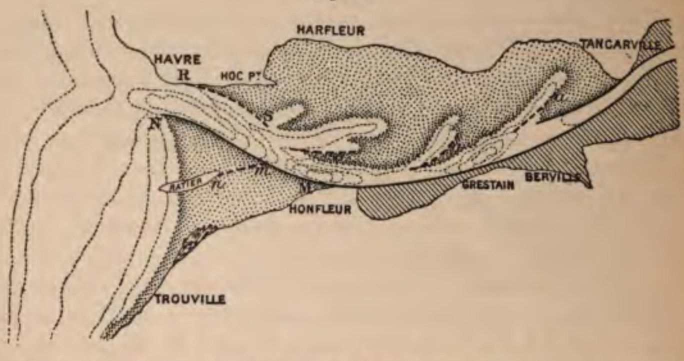
scheme to the test of his remarkable series of experiments; and Mr. Le Brun. without reopening the discussion as to which of the proposed schemes it would be advisable to adopt, he (Mr. Le Brun) considered that it would be advantageous to derive information from the results obtained, and that it would also be desirable to confirm them by supplementary experiments, which could be carried out in the large model of the Seine established at Rouen by the engineers of the Seine. The results obtained by Mr. Vernon-Harcourt showed that with the aforesaid scheme in the Seine model, *Fig. 13*, the flood-tide flowed at first towards Hoc Point, that a deep though small roadstead was scoured out in front of Honfleur, that the channel followed the training-wall up to Grestain, a little below Berville, where it diverged, probably owing to the flood-tide running towards the bottom of the bay, and

Fig. 13.

then came back between the training-walls near Berville, and that the channel though fairly regular had a small width. The anticipations, therefore, of the framers of the scheme were in a great measure realised; whilst it should be noted that the absence of the proposed concave training-wall, R S, had allowed the flood-tide to extend its action towards the north-east, whereas the probable effect of this training-wall would have been to turn the great depths towards the south-east, and to join the hollow of Honfleur, as shown in *Fig. 14*. The dredging of the portion of the Amfard bank within the trained channel, as intended, would have still further increased this effect. The bend in the channel at Grestain showed the necessity of modifying the action of the flood-tide, and it would have been interesting to try in the model the influence of submerged dipping dykes, *a a′ a″* as shown in *Fig. 14*, which would

Mr. Le Brun. probably have pressed the channel against the training-wall.[1] Mr. Vernon-Harcourt, in his own scheme, appeared to have doubled the width between the training-walls above Berville, and he had certainly obtained remarkable results; and it would have been interesting to have tried this modification with their project, which probably would have both widened and deepened the channel. The low training-wall M N in their scheme, *Figs. 13* and *14*, was necessary, and appeared adequate to secure the direction of the channel between Honfleur and Havre, whereas the breakwater, N P, *Fig. 13*, seemed to promote too great an amount of accretion in front of Trouville. By raising the concave training-wall M N above high-water, and dispensing with the breakwater N P, the sands outside would settle behind the Ratier bank; and this deposition might be hastened by a low dyke *m n* between the Ratier bed and the training-wall. A certain amount of water

Fig. 14.



surface in the estuary would undoubtedly be lost, but, on the other hand, the protection of the channel would be more effectually secured; and direct experiment would show whether these anticipations were justified. It appeared that the training-works in the upper part of the roadstead, added by Mr. Partiot to the scheme under consideration, were unnecessary, and in any case should be deferred until it was considered advisable to let only the clear water coming from Cape Antifer and La Hève enter the estuary. The experiments with models, which he desired to see completed, would enable the correctness of his hypothesis to be determined, or in any case to obtain a solution of the problem he had put forward, and the importance of which was evident. It

[1] Mémoires de la Société des Ingénieurs Civils, 1888, vol. i. pp. 294 and 313.

was to a great extent within the power of the engineer to modify, to diminish, or even to suppress transverse currents; and, on the other hand, he could create them, concentrate them on a given point, or distribute them over a long overfall. There was, accordingly, a considerable force in the tide, which should be always taken into account, and which could often be utilized with advantage, and which, consequently, it was most important to understand fully. He would, however, go still further, for the experiments already carried out demonstrated the possibility of reproducing natural phenomena in all their complexity with small-scale models, which opened out a vast programme. Could not these investigations be carried out in a rational manner by commencing with simple phenomena and proceeding to their combination? Taking only a single example, the silting-up in a bay might be investigated according as it was more or less open, and according as a stream flowed into it or not, of which the discharge varied; and the influences of winds, currents, and tidal range might be noted. These investigations, judiciously chosen, would rapidly augment the range of existing knowledge, and the number of undoubted rules which collective experience had already enabled congresses to draw up; they would enable maritime schemes to be entered upon with greater promise, and they would effect the solution of problems hitherto considered insoluble. Where still powerless, they should be supplemented by observation, for comparison, analogy, and experiment were the means of progress of the physical sciences. Mr. Le Brun.

Mr. W. Dyce Cay had previously given his observations and conclusions as to the formation of, and remedy for bars at the mouths of tidal rivers.[1] He felt some interest in the schemes for the improvement of the mouth of the Seine, as Mr. Partiot had sent him some of his writings last year; and the plan he should consider best differed in some important respects from that shown by Mr. Partiot in Fig. 4, Plate 4. He would construct a north breakwater extending from Cape La Hève, at a point about 4,100 yards north-~~east~~ from the Havre entrance, in a south-south-west west
direction, the same as the line of the Hève lighthouses, for 6,000 yards. Also a south breakwater, extending from Villerville on the south coast for 8,600 yards, in a north-west direction; these two breakwaters to form enclosing arms for the mouth of the estuary, with an entrance 1,300 yards wide. Inside of them, he would train the channel in a tolerably straight course, mainly by Mr. Cay.

[1] Minutes of Proceedings Inst. C.E., vol. c. p. 180.

[illegible] Seville. The [illegible]

[illegible] was [illegible] and therefore, [illegible] in Mr. [illegible] Mr. [illegible] were valuable [illegible] It was [illegible] were [illegible] to bring for- ward [illegible] such as the divergence [illegible] as to the best method [illegible] of the Seine. Mr. [illegible] the training-walls [illegible] ingenious experiments [illegible] and flow, had confirmed [illegible] was the [illegible] flood-tide, and for [illegible] with as little [illegible] and with an increase in [illegible] to overcome the [illegible] of the fresh water. The [illegible] of Rouen by the training-walls [illegible] further augmented [illegible] The rising tide would be [illegible] a portion of the flood-tide [illegible] positions which, being [illegible] current to desert its old channel, [illegible] main channel so injurious [illegible] these wanderings had the advantage of [illegible] surface of the estuary [illegible] of the sandbanks, [illegible] of the sea, and thus [illegible] of the vast estuary, [illegible] Mersey estuary. The [illegible] of the training-works would [illegible] to fresh [illegible] loss of flow at a high [illegible] compensated for by the [illegible] and the later [illegible] remained in the bay, would render its scouring action [illegible] efficient, as the tide would have had time to fall lower. [illegible] at a certain distance up the Seine the low-water line was higher at springs than at neaps, owing to the larger mass of tidal water not having

to flow away, it appeared that at spring-tides, when the ng out of the estuary was mainly effected, there was an s of tidal water, and that some silting up was accordingly sible. Besides, a widening-out of the training-walls, so as ne close to Havre on the one side and to Honfleur on the would not greatly curtail the existing tidal capacity; and would be compensation for any loss of capacity, in the ning of the channel and in the freer ingress of the flood-tide. objection might be raised that storms also would disturb the ore, and that the tide also might possibly increase somewhat lence. To this it might be replied, that the Seine estuary veritable gulf or an arm of the sea, with no pretention to e wholly a refuge harbour—a duty which devolved upon with its proposed extensions; that favourable periods could ected for future dredging operations in the estuary; and that, the bore was only dangerous at known times, of which s navigating the Seine were duly warned; and as it was a result of the tide, it would be inconsistent to try to exclude ilst favouring the admission of the tide, unless some movable was invented strong enough to resist it. Prof. Gaudar

only further criticism remaining to be made of Mr. Vernon-urt's scheme related to the great width left at the outlet, in d to the conveyance of the sands to the sea; for the ebb current, ling out like a large fan, would lose its scouring efficiency, and l leave too much of the necessary deepening to be effected by ing. It was here that Mr. Partiot intervened with his wed outlet; and immediately that the ebb was given only oint of issue, the waters would be forced to converge to this from a distance, and to maintain a fixed, deep channel in irection. Similarly the flood-tide, in seeking the neck, would the bar over which it would otherwise only glide. This seemed the more plausible as Mr. Partiot supported it by vations on a certain number of rivers; but, on the other hand, ok little account of Rouen, probably considering that the s of that port had been already amply satisfied, and that it othing to fear from new works. Mr. Partiot suggested that t width of channel was less needed for the propagation of idal wave than an adequate section, and that it would be as good to give the flood-tide a narrow and deep opening as at width of shallow entrance with its retarding frictional ance. This remained to be seen; and, moreover, would the nsation of sectional area be sufficient? Next, in the case seething and eddying mass of water resulting from the

Prof. Gaudard. dynamical inrush, it would be hazardous to rely on formulas of flow through narrow orifices. Mr. de Coene, an advocate of Mr. Partiot's scheme, said that it would be a mistake to compare the propagation of the flood-tide in the Thames and in the Seine, because in the Thames, the tidal currents entered precisely in the direction of the mouth; whereas in the Seine, the filling of the estuary was effected by derived currents, more or less interfered with. Nevertheless, however carefully the course of the currents was studied, and the entrance placed in the most favourable direction, it was difficult to admit that a long breakwater placed across the estuary, whilst affording shelter from storms, would not also to a great extent arrest the acquired impulse of the masses of water coming from the ocean and discharging themselves into the estuary, and that there would be no loss in the backing up of the fresh water, and no diminution in the distance to which the flood-tide extended up the river. It would, indeed, be a sheltered roadstead, and too well sheltered. On approaching the coast, the flood-tide was far from being a geometric wave, where the molecules revolved in closed orbits without advancing; it was really an inrush, and wherever a creek existed to be filled the current had to travel there. The leading idea, however, of Mr. Partiot was to convert the estuary into a large natural sluicing-basin, superior to an artificial sluicing-basin in possessing an enormous volume of water, and inferior to it in not having the power to introduce the mass of water, and let it loose, at the most suitable periods. At Honfleur, a sluicing-basin, 143 acres in extent, had been reclaimed from the estuary, the filling and emptying of which was regulated by movable openings at different places. Its filling was effected over a weir, admitting only the top cleaner layers of a high tide, so as to prevent the ingress of sand, involving a certain checking of the flow which was quite allowable when it was not a case of receiving a tidal impulse to be transmitted at once to a distance. Moreover, the emission of the water for scouring the entrance-channel to the port, by opening the revolving gates, was only effected when a good fall was obtainable, by the lowering of the tide, for creating a powerful current which acted upon the bed of the channel when least protected by a superincumbent layer of water. Being unable to erect an immense movable weir in the sea, to regulate in a similar manner the enormous scour of the Seine estuary, Mr. Partiot had aimed at doing what he could with fixed works. His breakwater would, indeed, keep out a portion of the sands during the flood-tide; and during both the flood and ebb, the narrow opening would concentrate into itself the scouring

currents; but as this opening could not be temporarily closed so as only to let out the water after the fall of the tide outside, the ebb would to a great extent be dissipated by slow and feeble outflows, as at first the current would be weak and the sandy bottom too much covered with water. Accordingly, most of the tidal water entering the estuary would be of little service in its outflow, beyond delaying the descent of the upper waters till these had acquired some energy; but since, under the existing conditions, the tidal water had not time enough at springs to flow fully out, this would be still more the case with the narrow outlet. There would, therefore, be a violent scouring current near low water; but the effect of the narrow outlet would be in excess, since a portion of the tidal water enclosed would remain inside unused, to be driven back by the ensuing flood-tide. Instead, therefore, of erecting a breakwater, it might be preferable to form a low cross-dyke, only slightly raised above low water; for if this sufficed to concentrate in the neck the scouring action of the strongest current for deepening the channel, the upward impulse of the flood-tide would be no longer materially impeded, because the flood-tide did not attain a high velocity till past half-tide, and as soon as the low dyke was overtopped it would flow freely over. From this it seemed that the schemes of Mr. Vernon-Harcourt and Mr. Partiot were not irreconcilable, but that, on the contrary, they would supplement each other, in a happy manner, carrying them out, moreover, cautiously in low lines, capable of being subsequently raised to some extent as experience might dictate. Thus the river training-walls would be prolonged in a funnel shape, greatly expanded so as to come to each side of the mouth; and then all the middle part of the opening would be barred by a long low dyke facing the sea, and leaving preferably two passes instead of one, near the shore on each side, closing the central channel between Amfard and Ratier, and trying to deepen the other two, and to convert the bed of the estuary into two arms of a delta, ensuring deep-water access both to Havre and Honfleur. The low dyke would partially arrest the sands brought in by the flood-tide and the waves, which would form a triangular bank on the sea side; and it would also retain a portion of the sand in the estuary brought down by the ebb, which would likewise form a triangular deposit on the upper side of the dyke, the whole forming a central island, bare at low tide, with the dyke in the middle. It was probable that the side channels, after having been primarily deepened and regulated by dredging, would maintain themselves; because, though the tidal currents only attained their full force

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Prof. Gaudard. during the latter half of the flood and the ebb, the low dyke and sandbank would scarcely interfere with the flood, beyond preventing its bringing up so much sand, and would intensify the scouring effects of the ebb on the deep channels. The progress of such great works was necessarily slow enough to enable them to be carried out in some measure as trial stages, which, by watching the first results, could be continued or modified, or even stopped, if at any point the anticipations were falsified. It was, moreover, desirable to extend the experimental methods referred to by the Authors. The small-scale models of Mr. Vernon-Harcourt were a resource where trials on the spot were not available; but the latter were clearly to be preferred when practicable, such as the wattlings of the Garonne mentioned by Mr. Partiot. For providing more solid trial structures in exposed situations, and which might, nevertheless, be removed and used again if unsuccessful, hollow concrete blocks in the form of a trough, like those employed by Mr Möller for the breakwater at the free port of Copenhagen,[1] might be used, which could be raised again by the floating crane which deposited them.

It had been pointed out by Mr. Vernon-Harcourt that the 5- and 10-metre lines of soundings at the mouth of the Seine had receded seawards 3 miles and more within sixteen years—a condition which it was urgent to remedy. The Loire estuary had given rise to similar apprehensions, more particularly as both sand from the sea and alluvium from the river came into it. Whereas Mr. Partiot, in 1871, had noted a certain stability in the depth of the channels under the action of the tides,[2] Mr. Carlier stated in 1878 that the deep places were filling up unceasingly, that the accretions exceeded all expectation, that an extension of the training-walls seawards could only hasten the growth of the banks in front of St. Nazaire, and that the only remedy was a length of ship-canal.[3] Now, as pointed out by Mr. Vernon-Harcourt, when by the construction of this canal they had avoided pushing the sands further down the estuary, deposits tended to form between La Martinière and Painbœuf, which would involve a considerable amount of dredging to keep them down, unless means were found of stopping or reducing these deposits. The important point was to reduce as much as possible the drift of material in the rivers all along the coasts, by means of groynes

[1] London Maritime Congress, 1893, Minutes of Proceedings, Section I, pp. 38, 39.

[2] Annales des Ponts et Chaussées, 1871, (i) p. 233.

[3] *Ibid*, 1878, (ii) pp. 595 to 612.

along the sea-coast, spurs, dykes, protection of the banks of rivers flowing through plains, and, lastly, dams in steps across torrents and the reafforesting of mountain slopes—works directed, in the first instance, to the protection of land from erosion, but the benefits of which extended to great distances by reducing the deposits which were injurious to navigation and promoted floods. The Loire was charged with materials coming direct from the denudation of the mountain slopes of Auvergne and Forez, or which had been eroded from its banks formed of the alluvium which had been brought down long ago. Mr. Partiot had pointed out, in 1871, that the works for securing the banks of the Allier, whilst protecting existing lands and reclaiming fresh lands for agriculture, would greatly reduce the sediment of this river and of the Loire. Prof. Gaudar

Much had been already done to regulate mountain torrents, especially in France and Switzerland, with great advantage to the plains. Mr. Vernon-Harcourt had furnished an interesting example of the consolidation of a large river in his description of the improvement of the Lower Rhone. The immediate object was to facilitate navigation by scouring the bed; but directly the cross-dykes from the sides formed enclosures where the materials scoured from the central channel lodged, the banks of the river were thoroughly secured in the places where formerly they were subject to erosion. Taking account also of the silting-up in the Durance and the Isère, as well as the dams and the replanting on the mountains effected in the Lower Alps, it seemed fair to infer that the Rhone at present carried less materials to the sea than it did at the period of the abortive attempt to lower its bar. Accordingly, if the works had been postponed, they would have possessed a better chance of success, in addition to what they would have gained by adopting the Roustan branch, and leaving the flow of the other channels of the delta unimpeded.

On some sea-coasts it might be possible, by the energetic and persevering efforts of all the riparian owners, to carry out works which, though small in themselves, might simultaneously effect protection of the coast, acquisition of land, and an improved access to ports at some distance off. Thus Mr. Partiot, in Fig. 7, Plate 4, had made the interesting suggestion that groynes, besides protecting land subject to encroachments by the sea, might serve, on coasts where the drift of sand was great, to gain tracts from the sea; that these reclaimed tracts, by their projection merely, would absorb this drift and dissipate its source; and that these ports would be delivered from this disabling encumbrance, which necessitated the constant opening out a deep passage for vessels

dard. across inexhaustible accretions. Dredgers would undoubtedly be always available; but, wherever practicable, the forces of nature should be turned against themselves before resorting to the costly and artificial method of dredging. In default of the power to arrest the littoral drift, attempts had been made to combine its free travel with the maintenance of the outlets of ports; but open jetties, the concave jetties of Mr. Bouquet de la Grye, and artificial sluicing proved too often only inadequate palliatives; and at Dunkirk, Ostend, and elsewhere, it had been necessary in the end to have recourse to great dredging operations. It, therefore, was a question whether there were not some places on sandy coasts where the principle of the late Sir John Coode's scheme for Port Elizabeth might be applied—of forming an island port by encircling breakwaters, sufficiently far out at sea to preserve its depth, and allowing the travel of sand to proceed unimpeded along the coast, to which the port would be joined by a bridge. This bridge, provided with lines of way, and, if desired, by endless transporting bands, would be raised above the reach of the waves, from which the port would also be protected by high parapets round the outer side of the breakwaters enclosing it. Ports had been formed quite as well, under favourable conditions, by extending quays into the sea as by excavating basins inland, the chief difficulty in the first case being to shelter the port from wave motion, and in the second case to secure the entrance-channel from accretion. Where it might be necessary for a proposed island port to have a large extent, and to comprise large quays as well alongside, the embankments for these quays might perhaps be formed by a temporary diversion of the sandy drift, by means of a dyke which could subsequently be removed to restore the primitive travel of the sand along the coast. Mr. Eyriaud des Vergnes, referring, in his Paper on "Ports on Sandy Coasts,"[1] to the proposal of forming an island port connected with the shore by an open viaduct, objected to it on the score of its great cost; but the question should primarily depend on the special configuration of the localities, which varied considerably.

The rule applied to the jetty system for lowering the bar at the mouths of tideless rivers, was the selection of one of the delta channels having a moderate discharge, and, consequently, bringing down only a moderate amount of sediment. In order, however, to carry out this principle to its full extent, a branch should be selected which could be closed at its head by a lock, and thus

[1] Annales des Ponts et Chaussées, 1889, (i) p. 185.

divert its discharge into the other branches, so that only the water from lockings would pass down, which would not involve much dredging for the maintenance of the depth over the bar, even in the absence of any littoral current. In this case it would be essential that the subsequent advance of the delta, through the mouths left open for the discharge, should be kept at a distance by groynes or otherwise, so as not to come back into the pass reserved for vessels. An important condition, moreover, would be that the head of the selected branch should be suitable for the construction of a basin in which the lock could be recessed, so that its entrance might not be liable to be impeded by the silt of the river. This really was the solution finally adopted at the mouth of the Rhone, except that, instead of excavating a canal, one of the existing channels would be utilized. Prof. Gaudard

Mr. Mengin-Lecreulx did not agree with the principle, stated by Mr. Vernon-Harcourt, that the formation of sinuous channels was inexpedient in tidal rivers of great width, and considered that it, at any rate, required explanation. The purely undulatory phenomenon which occurred on the first arrival of the flood-tide was, indeed, governed by special laws; but directly the tidal flow had become fully established, its action did not differ sensibly from that of the ebb current. The dual action noted of the two currents was manifested when the form of the channel was defective, and especially when the lines of the curves and the distances between the summits of the successive bends were not in harmony with the width. When this width was very large, it might be difficult in practice to establish this concordance; and, in his opinion, it was only in this sense that the above principle should be accepted. The case might more particularly arise at the mouth of the river, where the widths were greater, and where the problem became complicated by the close proximity of the sea and all the resulting perturbations. Higher up a river, and even for widths of 550 to 1,100 yards, he considered that a sinuous course was as applicable to tidal rivers as to others. Mr. Mengin-Lecreulx.

The rate of enlargement of some tidal rivers, with good outlet-channels, had been found by Mr. Vernon-Harcourt to range between 1 in 90 and 1 in 30; but these ratios of enlargement, especially if relating to English miles, appeared small. He himself had arrived, after a special study of this question, at ratios of between 1 in 50 and 1 in 20 per kilometer, according to the rise of tide, for rivers under ordinary conditions,[1] equivalent

[1] "Mémoire sur la Puissance Hydraulique des Fleuves à marée," P. Mongin. Congrès International des Travaux Maritimes, Paris, 1889, p. 23.

Mr. Mengin-Lecreulx. to between 1 in 31 and 1 in $12\frac{1}{2}$ per mile. The problem coul solved in each case by long, but simple calculations of volum effected by Mr. Franzius for the Weser, where he adopted a r of about 1 in 25 per mile for a tide rising $11\frac{1}{2}$ feet. F preliminary approximate calculation, the formula $\frac{\Delta w}{w} = 0$ $(1 + m)\frac{t}{d}$ might be advantageously used, in which w was the w of the low-water channel, Δw the increase in width per r d the mean depth at half-tide, t the rise of tide, and $1 + m$ proportion between the widths of the major and minor chan This formula agreed fairly with practical experience, and w applied to the Lower Weser, where t was $11\frac{1}{2}$ feet, $d = 23$ and $1 + m = 1 \cdot 33$, gave $0 \cdot 043$ as the rate of enlargement per r

If Mr. Partiot's Paper was merely intended to draw the at tion of engineers to narrow outlets and their effects, and to advantage of examining in each case whether it was pos and desirable to adopt this system, Mr. Mengin-Lecreulx ha objections to raise. The theory, however, had originated scheme proposed by Mr. Partiot for the Seine; and if, owin the great authority attaching to the Proceedings of this Institu this Paper should directly or indirectly furnish an argumen favour of this project, he could not possibly give it his appr In the first place, as Mr. Vernon-Harcourt had remarked, in case of great rivers and estuaries, the function of an arti narrow neck involved gigantic works, with corresponding ex diture; whilst the consequences of an error in the anticip results, which was always possible, became all the more formid The closing of the Seine estuary across a width of $6\frac{1}{4}$ miles, a bottom of a bay where very powerful tidal currents conve would involve an absolutely unprecedented work, the executi which, if not impossible, would at least be attended by formid difficulties, and expenses which would be hard to estimate.

As regarded its results, this scheme gave rise to grave quest Would not the narrow neck, placed at the side, occasion a lowe of the high-water level in the estuary, and what would be amount of this lowering; and what would take place du construction? Was not the formation of an inner bar to be ap hended; and by what works would the continuity of the cha in the estuary be ensured? What, moreover, would be the posi and depth over the outer bar, which would unquestionabl formed in front of the neck? These were all serious quest which had been for a long time discussed, and in face of w

the great majority of French engineers, the populations interested, and the public authorities, had decided against this scheme. Some deliberately condemned it as disastrous; whilst others confined themselves to the views that the risks and cost of construction would be excessive, that the chances of failure were too great, and that the results were uncertain and disproportionate to the works; but both sides arrived at the same conclusion. The examples from nature which furnished the basis of the argument in favour of the scheme were not complete; for the Loire, which had a neck, possessed only a very moderate navigable depth, whilst the navigation of the inner estuary of the Gironde was beginning to present difficulties. Beyond Liverpool, in front of which the Mersey flowed through a regular neck, a bar existed, sufficiently inconvenient for navigation to render it expedient to expend large sums at the present time in dredging for lowering it. The existence of a neck was not everything; and other conditions were needed as well. The port of Havre adjoined depths on the west and north-west, which were and would remain secure, and into which it would be very easy to open a deep outlet by a slight modification of its entrance, and by dredging in fine ground, which would provide a permanent improvement, constituting only a small portion of the works which Mr. Partiot's scheme would entail in order to provide a neck with the section absolutely necessary for the flow into the river. In Mr. Partiot's scheme, Havre was offered to have the waters of the Seine led to it, together with the materials they carried along, coupled with the promise that the current would drive the bar which would be formed sufficiently far out and into deep enough water. The maritime proposal, on the other hand, would afford economy, simplicity, and certainty; there was no doubt as to the choice, and it rendered the objection to Mr. Partiot's scheme absolute. As regarded the Seine, its improvement would be continued by rational means, less radical indeed, but also less dangerous, capable of being carried out in stages, and thus giving opportunities of profiting from time to time by the teachings of experience, which seemed to him in accordance with common sense. In conclusion, the plan of a neck was an interesting method to bear in mind, and to investigate, which had been usefully adopted in certain cases, though on a restricted scale, and which no doubt might again be resorted to; but it was not the sole method, nor of universal application, nor was it free from uncertainties. In large rivers and estuaries, the magnitude of the necessary works, the large scale even of the changes introduced in

Mr. Mengin-Lecreulx.

Mengin-reulx. the natural conditions, and the greatness of the risks attending any mistake with reference to the anticipated results, which were peculiarly difficult to predict, constituted very grave objections to Mr. Partiot's scheme, which would often lead to a search for other methods.

De Coene. Mr. J. DE COENE noticed that, in the Papers under discussion, absolutely dissimilar subjects had been touched upon, for rivers flowing into tideless seas, like the Mediterranean, had been considered at the same time as rivers flowing into tidal seas; whereas the action of the currents in the two cases were entirely different, and he proposed to confine his observations to the latter class of rivers, such as flowed into the sea along the French coasts bordering the Atlantic and the English Channel. He would observe at the outset that Mr. Vernon-Harcourt and Mr. Partiot had not mentioned in their Papers the experiments made upon the Seine, in imitation of those carried out by Professor Osborne Reynolds, who, by experiments, subsequent to those on the upper Mersey estuary, demonstrated the perfect concordance of results obtained with models of different scales—an evident proof of the indications that might be obtained by means of a model as to the direction in which training-walls should be carried out in the estuaries of tidal rivers. Professor Reynolds, in the later experiments carried out at Manchester, had reproduced in a V-shaped outlet changes of channel such as took place in the Seine estuary, and which constantly occurred on the Tees previously to the works carried out by the late Mr. John Fowler, and to which the Seine was still exposed, since recently the channel had suddenly shifted some miles in a few tides, passing from the north to the south of the bay of the Seine. Thus the channel which, on the 2nd of February, 1893, passed between the banks of Ratier and Amfard, changed abruptly in less than a week, in March, to the north, running close to Hoc Point, and having its outlet close to Havre. Then suddenly, on the 1st of May, it shifted to the south coast between Ratier and Villerville, where it was at the present time. These displacements traversed a width of estuary of about 4 miles. At certain places the channel changed nearly every day, and necessitated constant alterations of the buoys. It was these changes of direction of the channel which prevented its deepening, and confirmed the accuracy of the results observed in the experiments on the models of the Seine. As stated in his report on the Proceedings of the London Maritime Congress,[1] the experiments

[1] "Rapport sur les Travaux du Congrès International des Travaux Maritimes, Session de Londres, 1893," J. de Coene, pp. 21, 22.

made at Rouen with a large-scale model indicated clearly the Mr. De Coene. advisability of constructing a breakwater enclosing the Seine estuary, and leaving only an opening in front of Hoc Point, so as to scour the silt from the estuary, taking care to begin with a low training-wall along the south side, and to defer the construction of the training-wall beyond Honfleur on the north side, as Mr. E. de Churruca of Bilbao had advised them to do.[1] The same thing resulted from the opinion expressed twice by Mr. Vernon-Harcourt, first in his Paper on his little model of the Seine, and again in his Paper on his Mersey Model.[2] In the portion of this latter Paper headed "Introduction of Training-Walls in the Lower Estuary," Mr. Vernon-Harcourt referred to the results that might be obtained on a sandy bar by dredging, as gathered from the improvements in depth effected at the approach to Dunkirk Harbour, but expressed a doubt whether the results would be equally satisfactory in Liverpool Bay. He explained that his reason for adopting diverging training-walls in his experiments was that converging walls in Liverpool Bay would involve an enormous expense, but added that these converging walls would certainly be preferable. He said, "There is no doubt, as amply proved by the results of scheme A in the Seine experiments, and by the experience of the effects of converging walls at Dublin Harbour and elsewhere, that walls converging on the bar would deepen the channel over the bar. The wall or embankment, however, on the western side would constitute a gigantic work, about 7 or 8 miles in length, and traversing deep water for some distance; and both walls would be fully exposed to the sea." The opinion of Mr. Vernon-Harcourt on the action of converging breakwaters was worth recalling, for it would be found that these converging breakwaters always afforded great depths, as illustrated by the new experiments made at Rouen on the model of the Seine. As stated in his (Mr. de Coene's) pamphlet of 1890, Mr. Vernon-Harcourt's experiments were to be repeated by the Government engineers at Rouen with a larger model. These experiments had been commenced at the end of 1890, and were now in operation; and he had become convinced, by an examination of the model, that the adoption of a scheme with a narrow neck would afford a depth of 21 feet from Tancarville to the outlet between the breakwaters. The depth increased in an outer roadstead of 7,500 to 10,000 acres, where, over a large area, it amounted to 50 feet below

[1] "Étude sur les Expériences de M. Vernon-Harcourt, et le Congrès Maritime à l'Exposition," J. de Coene, 1890, p. 11.

[2] Proceedings of the Royal Society, vol. xlv. p. 514; and "Effects of Training-Walls in an Estuary like the Mersey," 1890, p. 7.

Mr. De Coene. low water. A shoaling occurred some distance from the outlet, forming a bar which, however, did not rise within 26 feet of the zero of the charts. As the sea very rarely fell below this zero, the Seine would be accessible at all times to vessels drawing over 26 feet of water. Moreover, the employment of powerful dredgers, like those at work on the Mersey bar, would enable the bar to be lowered, and the channel between the walls to be deepened, so that vessels could get up as far as Tancarville at low water. A deep roadstead would thus be provided in the Seine estuary, where the naval and commercial fleets would find a safe and efficient refuge. This was the scheme which he had already advocated in 1886 and 1889, and which had now emerged from the region of speculation. It might be expected that the official results of these experiments would be soon published, and that the solution which he advised would be carried out; and the Port of Havre would thus be accessible, by a new entrance into the Seine, at all times to vessels of 28 feet draught, like the Scheldt from Flushing to Terneuzen, and the Maas up to Rotterdam. The navigation also on the tidal Seine up to Rouen would be assured at every tide, as in the most favoured ports of the world. Accordingly, it was now certain that the project to be adopted should consist of a breakwater starting from Villerville, and stretching out to the Amfard bank; the training-walls also should widen out from Tancarville to a width of 4,290 feet opposite Honfleur, instead of 1,970 feet as proposed in Mr. Partiot's project of 1859, and the south training-wall should be prolonged to the Amfard bank, an opening being left at the outlet of the Seine into the sea, 8,860 feet in width. The enclosing breakwater might be formed of fascines, as employed on the Weser, and at the jetties at the mouth of the Maas, which would enable it to be constructed cheaply, rapidly, and solidly, and thus ensure the creation of a roadstead in the Seine estuary of great depth and with a fixed channel.

One point had not hitherto been dealt with by the engineers who had discussed the subject, namely, the way in which the works should be carried out. Mr. Caland, the eminent engineer of the River Maas improvements, had remarked to him that the works for the completion of the improvements of the Seine should not be carried out like the works above. In an estuary like the Seine, the works, at the point they had reached, should not be extended from above downwards, as in the upper part of the river, but from the sea upwards, as had been done on the Maas, where the cut across the Hook of Holland was undertaken first, and also on the Tees in constructing the breakwaters on the sea-coast. Having

first fixed the outlet of the river, the interior works would be carried out much more easily and cheaply; whereas in proceeding from above seawards, almost insuperable difficulties would have to be overcome. Moreover the partial closure of the mouth of the Seine was justified by the tradition which indicated that the Seine estuary was formerly deep and stable as far as Harfleur, at a period when the outlet was closed between Villerville and Ratier by a tongue of land covered with trees, for at low tide traces were found in this part of the remains of an ancient forest, showing that in ancient times the Seine had not as large a mouth as at the present time. This bore out the schemes which he and Mr. Le Brun had advocated in the discussion at the Société des Ingénieurs Civils in 1886 and 1889, and which Mr. Partiot had proposed in 1859, but with insufficient widths for the easy admission of the flood-tide. The estuary of the Seine thus enclosed would form a vast roadstead at its entrance, where the flood-tide spreading over a large area and providing a large volume of water at high tide, would furnish the vast reservoir which Mr. Wheeler considered necessary for the maintenance of the entrances of tidal rivers. The new widening-out between the training-walls, in accordance with the opening left at the outlet into the sea, would thus afford a continuous enlargement of the channel out to sea, facilitating the introduction of the flood-tide into the river. The results, accordingly, asked for in the discussion on this subject at the inland navigation congresses, at this Institution, and at the sister society in France, would be realised. Mr. De Coene

Baron Quinette de Rochemont

Baron Quinette de Rochemont considered it was unquestionable that the depths in a narrow neck were relatively larger in most cases, as this was the natural effect of any narrowing of a current; but these depths only extended a certain distance below and above, beyond which they shoaled in proportion to the local conditions, so as almost always to form a bar. The depth of water on this bar was generally much less than in the neck, and in many cases too little for vessels to enter the river at all times. Though there was a minimum depth of 40 feet over the bar of the Gironde, and 28 feet over the Humber bar, on the other hand, at the entrance to the Loire, the depth over the bar at low water was only 11 to 13 feet, and in front of the Tagus only 19⅔ feet. The important question, therefore, for navigation was not the depth in the neck, but the depth over the shoals below. A study of the maritime charts showed that a number of rivers with a neck had only small depths at their mouths, as, for instance, the Loire, the Adour, the Liffey, the Senegal, &c. On the contrary, many rivers with funnel-shaped

Baron Quinette de Rochement. outlets possessed great depths at their mouths, as, for example, the St. Lawrence, with a minimum depth at low water of 330 feet, the Thames with a minimum depth of 27 feet over its bar, the Forth with 88 feet, and the Congo with 164 feet. The analogies cited were often misleading, for rivers almost always exhibited contractions followed by expansions near their mouths; and they were, therefore, liable to be classed as estuaries with a neck, or funnel-shaped, according as they confirmed or not the theory put forward. Special attention should be paid to local conditions, which varied so much in different rivers; and therefore he could not admit the comparison, instituted by Mr. Partiot, between the Foyle and the Seine, whose conditions were absolutely different.

The waters of the Foyle were clear, carrying no alluvium along; and all the prevalent winds were in the opposite direction to the entrance to the bay. The mouth of the Seine, on the contrary, received all the drift from the sea, for the flood-tide, whether coming in from the north or south, was densely charged with materials, and the prevalent winds blew right into the estuary. Moreover the currents in front of the Foyle flowed transversely to the neck, instead of converging from all sides towards the mouth, as in the Seine. The little counter-current, caused by the projection of Cape Inishowen to the east of the neck of the Foyle, was merely a local peculiarity, which could not be compared to the reverse current occurring in the northern part of the mouth of the Seine, at the moment the filling of its estuary was completed.

The construction of a breakwater in the estuary of the Seine, connected with the southern shore near Villerville, would seriously disturb the *régime* of the currents and the tides. The current passing along the coast of Calvados, and continuing its easterly course till high water, would be diverted northwards; and the reverse current would occur sooner, would increase in strength, and would arrive in front of Havre more charged with sediment. There, meeting with currents flowing in other directions, eddies would be formed, causing loss of velocity and the formation of shoals in front of the neck. The filling, also, of the Seine and its estuary would take place under conditions difficult to foresee, since it should be effected by the waters which actually flowed northwards about an hour before high water at Havre. The rise of tide in the Seine might be diminished; the water would attain a higher level in the south than in the north of the estuary; and it was likely that the second high-water would cease, to the great detriment of navigation. Moreover, the flood-tide, laden with sand collected from the banks below, would bring materials into the

estuary, which would be deposited at slack-tide, and would accumulate in the sheltered recesses, from which it would not be displaced by the ebb. The capacity of the estuary must be thus gradually diminished, to the great detriment of the depth over the bar, which would be formed below the neck. The port of Trouville, also, would be irretrievably destroyed, and the port of Honfleur would run a serious risk of a similar fate. Baron Quinette de Rochemont.

It had been stated that the shoal below the neck, if it was formed, would be situated where the depth of the water was great, and therefore could not be any impediment to navigation. Undoubtedly the shoal would form in a position where at present there was a fairly considerable depth at low water; but probably only a relatively short time would elapse before the shoal was sufficiently raised to form a serious obstacle to navigation. The Seine bank, indeed, which stretched out to sea in front of the mouth, furnished an inexhaustible supply of sand; this bank supplied the 460,000,000 cubic yards of sediment which had been deposited in the estuary in a few years; and from this bank would come the alluvium which would form the new shoal. It would be impossible to state beforehand the precise height that the bar would attain; but there was every reason to fear that the depth over it at low water would be inadequate for the free passage of vessels at all states of the tide. In fact, such a depth was rarely found in rivers more favourably situated as to tides and alluvium than the Seine.

The project, accordingly, proposed by Mr. Partiot for the improvement of the outlet of the Seine was of a most risky character. This conclusion had, moreover, been confirmed by the results of experiments with small-scale models of the Seine, made first by Mr. Vernon-Harcourt, and subsequently by Mr. Mengin-Lecreulx. On the contrary, the improvement of the outlet of the Seine could only be effected by facilitating and regulating the influx of the tide, by means of training-walls widening out rapidly, and by lowering the shoals existing in the channel.

Mr. L. L. Vauthier remarked that the laws governing the motion of the waters on the surface of the globe were everywhere identical, with only those modifications which differences in cohesion and density might introduce. In spite, however, of this absolute identity, the diversities in surrounding conditions, and variations in the numerical factors exercised such an influence on the phenomena, that at first sight, especially in regard to the complicated case of the outlets of tidal rivers, each appeared to constitute a special problem. The variety in the numerous physical conditions Mr. Vauthier.

Mr. Vauthier. affecting the mouths of tidal rivers gave to each tidal outlet its special features, which authorised regarding with suspicion a system which was supposed to be applicable to all tidal outlets without distinction. He would admit that the restricted outlet, advocated by Mr. Partiot, might be adopted with advantage, within reasonable limits, for the mouths of tideless rivers, and might even be expedient for rivers with a large fresh-water discharge, flowing into seas with a small tidal range, provided that each case was separately considered. Where, however, owing to a great rise of tide, the most potent factor in the maintenance or creation of a good navigable depth in the river was the volume of tidal water introduced by the flood-tide and expelled by the ebb, it appeared to him difficult to allow that it could be expedient to make the flood-tide first pass through a narrow neck to effect an improvement. This was the sole point which he proposed to consider; and as Mr. Partiot specially proposed to apply this theory to the Seine, he would take the mouth of the Seine as the basis of his argument. At the close of his Paper, Mr. Partiot acknowledged that the increase of the volume of the flood-tide to its utmost limits in ascending a river was advantageous; and so far he (Mr. Vauthier) entirely agreed. Mr. Partiot, however, added that the divergence in opinion between him and his opponents, as to the form that should be given to mouths, was partly due to their not having sufficiently taken into account the fact that the progressive increase of the sectional area of the channel was of far greater importance for the free influx and efflux of the tide than its increase in width. Although the introduction of tidal water into a river, followed by a partial driving back of the fresh-water discharge, was a purely hydraulic phenomenon, rather than the propagation of the tidal wave, he would nevertheless be disposed to admit with reservation Mr. Partiot's statements on this point, whilst noting that partial contractions of a river always produced injurious losses of momentum. Where, however, was the progressive increase of sectional area on which Mr. Partiot relied? It was expedient at this point to put aside vague general affirmations, and to examine in detail a particular case, as he would do in the case of the Seine. The general condition of the Seine estuary had been described in various publications.[1] The systematic regulation of the banks,

[1] "Rapport sur les Améliorations dont sont encore susceptibles la Seine Maritime et son Estuaire," L. L. Vauthier, Rouen, 1881; "La Seine Maritime et son Estuaire," E. Lavoinne; and Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 241.

and the dredging of shoals carried out above Quillebeuf since 1880, had increased the tidal volume, and diminished the drop of the high-water line between Quillebeuf and Rouen; but the desirable widening of the trained channel, to which the raising of the high-water line of spring-tides below Quillebeuf and its depression above were attributed, had not yet been effected. Mr. Vauthier.

The scheme of improvement proposed by Mr. Partiot was shown on Fig. 4, Plate 4, and consisted in prolonging the existing training-walls without increasing the width between them, and in reducing the outlet to a width of about 2,190 yards, by a breakwater extending from Villerville towards Havre, with a bend seawards towards its outer end. Was this outer portion to be continuous as shown in the scheme of 1887, or was an opening to be left in front of the present entrance to Havre as shown on the plan accompanying the Paper; and was the low training-wall, prolonged from La Rille, to stop at Honfleur, or to extend towards Havre? These points, however, were only of secondary importance; and his chief concern in the present instance was the question of the filling of the estuary by the tide.

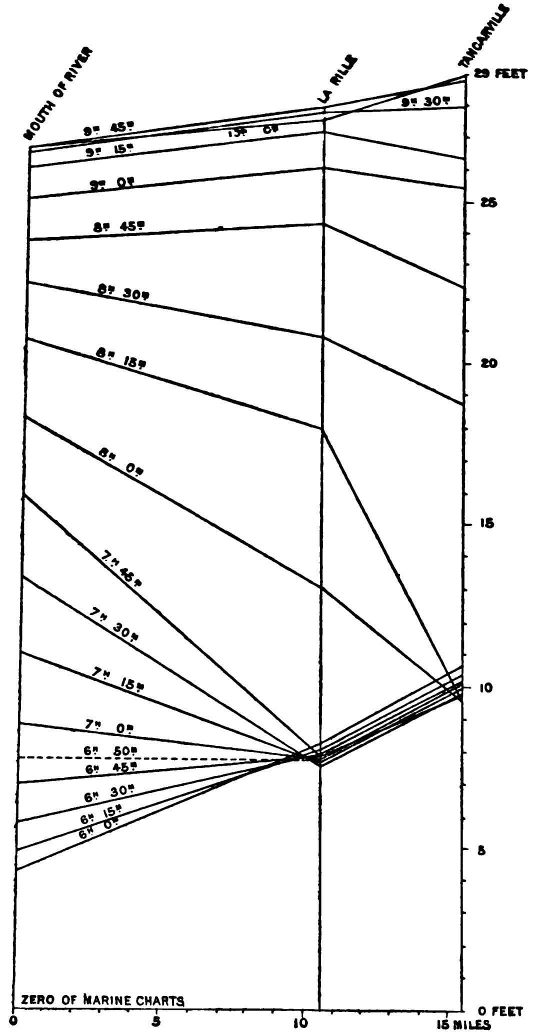
The volume of tidal water entering the trained channel at La Rille depended essentially on the conditions of the filling of the Seine estuary up to that point, and had little relation to the laws of the propagation of the tidal wave. The estuary, strewn with sandbanks, between which the ebbing waters flowed away through winding channels, was an empty space filled by the rising tide; and though under the existing conditions of two branch tidal waves, from the north and south respectively, combining to fill the estuary, it was possible that the final influx of water into the estuary might experience feebly the rythmic influence of the tidal wave passing along the southern coast, it was certain that, when once the estuary was barred, this kind of influence would cease entirely. There would only be an immense receptacle communicating through a neck with an infinite mass of water subjected to a definite tidal oscillation; and the first question was how the estuary would be filled through this neck, previously to the changes which the new works might produce. The volume of tidal water flowing at each tide into the estuary in 1875, was stated in his report of 1881 to amount to 906,000,000 cubic yards during an ordinary spring-tide, and 433,000,000 cubic yards during an ordinary neap-tide; and he also obtained, for the preparation of the same report, observations of the spring-tide of the 20th of September, 1880, and of the neap-tide of the 27th of September, 1880, taken at Havre, La Rille, and several other stations on the

Mr. Vauthier. river. To compare the cross-sections at the outlet at different heights of the tide, under existing conditions, and as modified by Mr. Partiot's scheme, he had adopted the meridian of Villerville for the present outlet, to be well within the mark; and he had assumed that the depth in the neck would be 16½ feet below zero at the sides, increasing to 41 feet in the centre, and exceeding 33 feet for a width of over 1,250 yards, which depths could hardly possibly be exceeded. Under these conditions, the cross-sections of the outlets increased between zero, or the lowest low water, and high water at springs, 26¾ feet above this level, from 32,120 to 114,990 square yards in the present estuary, and from 23,920 to 43,420 square yards in the proposed neck; whilst the ratios of the sections in the estuary to those in the neck increased from 1·343 at zero up to 2·643 at high water. Beginning with spring-tides, which evidently should give the most characteristic results, the tidal rise every quarter of an hour at Havre, La Rille, and Tancarville on the 20th of September, 1880, were indicated in the diagram, *Fig. 15.*[1] The diagram showed that, at the time of low water at the mouth, the tide was ebbing with a considerable slope from La Rille to the mouth; and as the tide continued falling at La Rille till seven o'clock thirty minutes, when the tide was 5 feet 10½ inches higher at the mouth than at La Rille; and, under these conditions, the tidal lines between La Rille and the mouth during those periods were clearly not straight but concave. In any case it was reasonable to assume that till the tide outside reached a height of 7 feet 7½ inches, represented by a dotted line on the diagram, the tidal current had not been reversed at the mouth, and that the estuary had not received any appreciable quantity of tidal water. The rise of tide from this level to high water, amounting to 19 feet 1½ inch, was effected in two hours fifty-five minutes; and the mean rate of rise every five minutes during this period was $\frac{19 \cdot 12}{35}$ feet $= 0 \cdot 546$ foot. The mean sectional area of the existing outlet between these heights was 82,860 square yards; and as 906,000,000 cubic yards had to flow in during the period of ten thousand five hundred seconds, the average velocity was $V = \frac{906{,}000{,}000 \times 3}{82{,}860 \times 10{,}500} = 3 \cdot 124$ feet per second. After six o'clock

[1] Besides the diagram, Mr. Vauthier's communication contains three numerical tables, the main results of which have alone been given, owing to want of space; and the length of the communication has rendered considerable condensation necessary in other respects.—SECRETARY INST. C.E.

fifty minutes, the fall towards La Rille remained fairly regular Mr. Vauthi
through seven-tenths of the total rise; and the most natural hypothesis was that the velocity of influx varied in proportion to

Fig. 15.



the rate of the rise of tide. As the most rapid rise in five minutes was 1·14 foot, or very nearly double the mean rate of rise, it followed that the maximum velocity of influx was 6·25 feet per

Mr. Vauthier. second, which did not appear excessive. These data enabled the depressions of levels that would occur in the estuary from the influx of the tide through a narrow neck to be calculated, from which results it appeared that with a spring-tide corresponding to that of the 20th of September, 1880, the maximum depression of $2\frac{3}{4}$ feet would take place at about half-past seven, at which time the velocity of flow through the neck would reach $13\frac{1}{4}$ feet per second, and that for less than a quarter of an hour during the rise after six o'clock fifty minutes would the depression be less than 9 inches, and the velocity of influx in the neck be less than $6\frac{1}{2}$ feet per second. Similar calculations, on the same basis, having been made for a neap-tide corresponding to that of the 27th of September, 1880, with a range of only $7\frac{2}{3}$ feet, indicated that the depressions of the water-level in the estuary due to the neck, and the velocity of influx through the neck, were comparatively very slight in this case, reaching a maximum of not quite 2 inches of depression, and $3\frac{1}{4}$ feet per second velocity of flow. Though the contrast in these respects between springs and neaps was very great, it was only the result of well-known laws.

The calculations of depression due to the neck assumed that the inflowing water started from a state of rest; but this hypothesis was not in conformity with the facts under existing conditions. The velocity of influx could not be created without some surface-depression; but this depression, which for the average velocity of $3\frac{1}{10}$ feet at spring-tides did not exceed $1\frac{4}{5}$ inches, began in the meridian of La Hève, more than $2\frac{1}{2}$ miles to the west of the meridian of Villerville, where the outlet was assumed to be; and when the entering waters traversed this, they had already received their impulse from the ocean, and did not undergo any fall there. This, however, was not so in the case of the neck. Formerly, when Mr. Partiot proposed to place the new mouth close to Havre, it might have been supposed that, at the first moments of the rise of tide, the waters would have approached the neck with an already acquired velocity, though extremely feeble and producing only a very slight effect. Nothing analogous, however, could occur now, even for this brief period, when the new mouth was under La Hève, right on the open sea; and in any case this was incontrovertible with still water, which the estuary had to draw upon to fill itself very soon after the beginning of the rise, when the branch of the flood-tide coming from the neighbourhood of Trouville would be stopped by the breakwater. The calculated depressions, therefore, were decidedly effective quantities, in which a coefficient higher than unity might clearly have been intro-

duced, in accordance with admitted facts relating to the flow of water. Mr. Vauthier

To complete the investigation fully, it would be necessary to calculate in stages how the estuary would be filled under the new conditions created by the neck, and especially how the inflowing water would reach the extremity of the trained channel at La Rille for ascending the river; but for his present object some general indications would suffice. At six o'clock fifty minutes the water-level was 7 feet $7\frac{1}{2}$ inches above zero, both at the mouth and at La Rille, *Fig. 15*, the outflow slackened at the mouth, and the filling of the estuary was about to commence; and, supposing the neck suddenly formed, what would be the result? Assuming that the rate of the rise of tide was uniform, a difference of water-level would be formed at each end of the neck as the tide rose, which would increase till it became large enough to remain constant. Calling H the height above the line of departure at which this result was reached, the average velocity of influx during this first period would be exactly two-thirds of its uniform value above H; and, admitting that the inner level had risen this same fraction of H, the amount of fall would equal $H \div 3$. The variation in the rate of rise modified the simplicity of this conclusion; but these variations altered very slightly the numerical result, if the sole ratio of the sections taken corresponded to the height $\frac{4}{9}$ H, a value to which a velocity equal to two-thirds of the average velocity of influx corresponded. Calculating on this basis with respect to the tidal influx due to the rise of $5\frac{2}{3}$ feet, comprised between the levels 7·61 and 13·26 feet above zero, which was about one-third of the total rise above the lower level, the loss of height was found to amount to $9\frac{1}{2}$ inches, equivalent to about 14 per cent. If instead of stopping at the level 13·26 feet, the layer of water taken into consideration had been carried up to 14·40 feet, thereby including in it the greatest rate of rise of 1·15 foot in five minutes, the depression would have amounted to 11 inches, involving a corresponding loss of inflow. These results, though somewhat striking, had been greatly reduced in amount by substituting mean rises for the actual irregular ones, since, taking this into account, at the time of the greatest rate of rise of tide there was a loss of 40 per cent. at this period, when the inflow was most active. The introduction of a neck at the outlet of the Seine would accordingly lead to two grievous results, namely, depression of the water-level inside the breakwater, and loss of tidal volume entering the estuary. The depression would, on the average, be more than $1\frac{1}{3}$ foot up to about nine o'clock, *Fig. 15*, at which time

Mr. Vauthier. the slope of the water-level in the estuary had become reversed, and sloped seawards, and the velocity of influx was slackened at La Rille, producing the rise in the water-line there which was observable near high water. The loss of tidal water entering the estuary, resulting merely from the circumstances considered above, would amount to more than one-fifteenth of the tidal capacity as calculated in 1875, or over 60,000,000 cubic yards; whilst the long period of high water at Havre after nine o'clock could not make up the deficiency, since at this period no more influx took place.

These conditions at the outlet of the neck would necessarily be reproduced at La Rille, which, in spite of Mr. Partiot's low training-wall in prolongation of the outer one, would still remain the real entrance of the river in his scheme. Reduction in the volume passing up, and a smaller tidal impulse were the inevitable consequences; for it would be impossible to obtain as large a discharge through the estuary with gentler surface slopes and a smaller volume of water. This impossibility would be still more manifest if the not inconsiderable loss of momentum, resulting from the abrupt changes of velocity in the current on emerging from the neck, were taken into account. The condition, therefore, thus created, would be extremely unfortunate for the tidal Seine; and as the effect in these cases always reacted upon the cause, the situation would before long become disastrous. Hitherto, indeed, he had only examined the filling of the estuary; but there was no prospect of the neck having a compensating influence on the outflow. Undoubtedly after a certain period of the ebb, the neck would afford an ample section for the efflux; but at the beginning of the ebb, when the estuary was nearly full, an obstruction to the outflow causing a depression of level, the reverse of that noted for the flood-tide, would produce a longer stagnation of the tidal water inside, and increase the amount of sediment deposited, without having any beneficial influence on the level attained, and on the volume of water expelled. The impediment, accordingly, offered by the neck to the influx of the flood-tide would be wholly injurious. The volume of tidal ebb and flow was, as acknowledged by Mr. Partiot, the great factor; and the effects of its reduction, though possibly gradual, would be certain; and without considering the other objections to the scheme, such as the difficulties of execution, and the formation of a bar outside, the immediate advantage upon which Mr. Partiot relied would be liable to disappear. Undoubtedly the first result of the formation of a neck should be a deepening within it, if the bottom could be scoured; but to what extent, and in what manner would this deepening

be extended outside as well as inside? Mr. Partiot had, indeed, indicated this in the illustrations accompanying his publications; but these anticipations could not be regarded as possessing any definite certainty. Moreover, should they be correct at the outset, if the effects he (Mr. Vauthier) had attributed to the construction were real, the benefit would be lost before long. Mr. Vauth

In order to justify his schemes for the Seine, Mr. Partiot relied upon analogies which he (Mr. Vauthier) would briefly consider, though he objected to this method of reasoning with regard to tidal outlets. In a very interesting review of the hydrographical conditions of the mouths of large tidal rivers, to which new examples were added in every fresh publication, Mr. Partiot put forward as the most conclusive analogies, the Gironde, the Loire, the Tagus, the Mersey, the Humber, the Foyle, the Maas, the Scheldt, and the Rio Grande do Sul. If it was true that the contraction caused by a neck could not fail to produce a lowering of the water-level at the entrance to a river, and that, in spite of the advantages attributed to this contraction, this depression was in itself a disadvantage, which appeared to him difficult to dispute, then the amount of the contraction and the tidal range were the principal factors in the results. For relatively equal depths, the proportion R of the restriction, either in a natural neck, or in a neck to be made, was a measure of the difference which this restriction produced between the free tidal influx and what might be termed the forced tidal influx. It might be supposed that a contraction of one-half might double the depth of the entrance channel; but it would be difficult to admit that a contraction of four-fifths would increase the depth five times. The factor R, therefore, it seemed to him, should enter as the first power into the comparison to be made between the several cases. The range of tide was one of the elements of the velocity of influx; and the mean value, V, of this velocity was in reality determined by the volume of inflow, and the average section of the entrance channel, which necessarily bore a certain relation to one another. Assuming this relation to be constant, which was favourable to small ranges of tide, and that the duration of the flood-tide was the same everywhere, that the velocity, V, was proportional to the range, and the resulting height to the square of the velocity, then the product RV^2 (RH^2, where H was the range of tide which, according to the hypothesis, always bore the same ratio to V) furnished a sort of module measuring the obstacle presented by the neck to the action of the tides. Putting aside the Mersey, which was quite a special case, and omitting the Maas and the Rio Grande do Sul, which did not appear to possess

Mr. Vauthier. contractions, the following were the values of RH^2 for the examples quoted by Mr. Partiot:—

Name of Estuary.	R.	H.	RH².
		Feet.	
Seine	0·75	23·6	418
Gironde	0·50	15·9	126
Loire	0·45	15·6	109
Tagus	0·80	12·0	115
Humber	0·35	18·7	122
Foyle	0·83	6·6	36
Scheldt	0·22	13·9	43

The highest modules after the module of the Seine, namely, those of the Gironde, the Humber, the Tagus, and the Loire, were only between one-third and one-fourth the module of the Seine with Mr. Partiot's proposed outlet, even on the assumption that the rise of tide took place, as at Havre, in less than four hours, instead of about five hours. Consequently, the lowering of the water-level due to the neck, which had been found to average 1·2 foot for the Seine, would be only 0·4 to 0·3 foot for the other outlets, compared with the water-level with an unrestricted outlet, which established a most important difference between examples which Mr. Partiot regarded as analogous. Moreover, the condition of the Gironde and the Loire, which Mr. Partiot desired to extend to the Seine, was by no means perfect. In spite of the very gentle inclination of its bed, the Gironde was very troublesome to deepen; and it was doubtful whether the works carried out at the Pointe de Grave, not to maintain the contraction, but for protecting the salt marshes of Verdon, were satisfactory; whilst the contraction of the estuary of the Loire between Mindin and St. Nazaire was unfortunately far from having made the Loire a model river. The remaining modules were too small to be worth discussing, whilst the seas into which the Maas, the Scheldt, the Foyle, and the Rio Grande do Sul flowed were almost devoid of a tide; and this fact, irrespectively of the other considerations so ably brought forward by the hydrographic engineer, Mr. Gaspari, at the nautical inquiry of August, 1886, on the schemes for improving the Port of Havre and the passes of the Lower Seine, deprived the Foyle of all value as an example, which Mr. Partiot was accustomed to put forward as his favourite instance. It was difficult to see what advantage in

support of his theory Mr. Partiot would derive from the Scheldt, as well as from the Mersey; for the Scheldt experienced only a very slight reduction in width in front of Flushing; and if the spacious estuary extending about 11 miles beyond was to be attributed to this contraction, it afforded little recommendation to the system of contracted outlets. Liverpool was situated on a narrow neck of the Mersey separating two estuaries, the inner one of which was not suitable for navigation; and the outer estuary which stretched 12½ miles seawards, was intersected by a number of channels, the deepest of which was impeded by a bar with a depth over it at low water of barely 10 feet, and which did not improve. If the tide at the mouth of the Mersey had not a range of nearly 30 feet, the Port of Liverpool would be in a critical condition, as English engineers admitted, and it furnished cause for anxiety; and it was, therefore, surprising that the Mersey had been cited on behalf of the theory of narrow necks. Mr. Vauthier.

Many important elements had been omitted from the preceding considerations, such as the inclination of the river-bed, which was generally small near the sea, and the more or less powerful and regular discharge of fresh water. The small rise of the river-bed inland was the most important factor in the good tidal scour of the Scheldt and the Thames. Thus the tidal rise of springs at London, 50 miles from the sea, was 4¼ feet greater than at the mouth of the Thames; and the tidal rise at Antwerp, 62 miles above Flushing, was about the same as at sea. The Gironde enjoyed a similar privilege, for at Bordeaux, 59 miles above the Pointe de Grave, the tidal range was similar to that in the open sea; and this circumstance furnished a better explanation of the relatively good condition of the Gironde than the contraction at its mouth. A more thorough investigation, including the discharges of fresh water, would probably exhibit new elements for a rational discrimination; but he, nevertheless, considered that the tidal oscillation remained the main basis of a classification which upset the theory which Mr. Partiot had wholly built up on the simple differences in plan of the mouths. River mouths at which the rise of tide exceeded 13 feet were not numerous; they were chiefly found in Europe, and only along moderate lengths of coasts. This amount of rise occurred only in a few places between Gibraltar and Brest; but it was found between Brest and the Scheldt, from the Scilly Isles to Aberdeen, with the exception of Poole, cited by Mr. Partiot, and near Yarmouth where the rise was only 5 feet; and along the west coast of Great Britain, up to half-way between *the Mersey* and the Clyde. Along the whole of

Mr. Vauthier. the west coast of Africa, there was only one place, in latitude 12° north, and on the east coast only in the Mozambique channel, and near Zanzibar, where the rise of tide of 13 feet was exceeded; and throughout the coasts of Asia, there were only isolated places where a large tidal rise occurred, such as north of Bombay, on the east coast of the Bay of Bengal, and Corea. On the coasts of America, there were very large rises of tide on the Atlantic coast at the two extremities, namely, in the Bay of Fundy and at Patagonia, with only two places along the intervening coasts where the rise slightly exceeded 13 feet, namely, near Boston, and Maranham in Brazil; and along the west coast of America, the tide rose high only at Cape Horn and a few other places. This summary indicated the parts of the world where examples of rivers with a good tidal rise at their mouths should be sought, which, if he was right, exercised a classifying influence on rivers. Such rivers were few in number, and formed a well-defined class requiring special treatment. Their mouths should be formed so as to facilitate to the utmost the influx of the tide, which acted spontaneously, like a powerful hydraulic ram, when once admitted, and which had not hitherto by any means been utilized to its full extent. These tidal waters entering an estuary were only useful if they also flowed out again, and deepened the navigable channel; but the channel of the ebb was by no means formed in the same manner as the best channel for the influx of the flood-tide. These kinds of outlets, accordingly, involved the solution of a double problem, namely, the creation of two distinct channels closely combined, one the flood-tide channel admitting freely the incoming tide, and the other the ebb-tide channel concentrating in itself as much as possible the out-flowing current. This difficult problem had never been fully investigated, and even then would only admit of partial solutions; but Mr. Partiot's theory had not advanced its accomplishment.

Mr. Vernon-Harcourt. Mr. L. F. Vernon-Harcourt, in reply to the correspondence, observed that Mr. Amor had referred to the property of sea-water, and, indeed, other saline solutions, of causing earthy matter to deposit much more readily than was the case in fresh water. Mr. Amor, however, had apparently not discovered the original account of the experiments referred to, which was contained in a report by Mr. Sidell, assistant engineer on the Mississippi survey, dated 1839, and published as an appendix in Humphreys and Abbot's "Report on the Mississippi River." The somewhat anomalous result was probably due to saline solutions producing an aggregation of clayey particles, and, consequently, promoting their rapid pre-

cipitation. The subject was of considerable interest with reference to the formation of bars at the mouths of delta-forming rivers, and was worthy of further investigation. Mr. Vernon-Harcourt.

The particulars as to the proportion of matter rolled along the bed of the Mississippi, objected to by Mr. Corthell, were derived from an article on the Mississippi by General Abbot, published in *The Encyclopædia Britannica* in 1883, and not from documents which appeared prior to the construction of the South Pass jetties. If, as stated by Mr. Corthell, the sediment was carried wholly in suspension in the current, the physical conditions were to that extent less unfavourable than he had supposed, and the improvement of the outlet of the South Pass a less difficult work. With regard to Mr. Corthell's criticism of the views expressed in his Paper as to the existing condition and prospects of maintenance of the 30-foot channel beyond the South Pass jetty channel, he need only quote a paragraph from the "Report of the Chief of Engineers for 1893," which he had only had access to subsequent to the reading of his Paper: "The chart of the sea end of jetties shows a gradual growth of the bar, and clearly indicates the early resumption of those conditions which obtained before the jetties were constructed. If it is therefore desirable to maintain the present 30-foot depth of channel through this bar, the early extension of the jetties is patent to any unprejudiced observer. It is possible that the 30-foot channel at the Gulf entrance may be successfully maintained a few years longer by energetic dredging, but it is evident that it will not be a great while before the prolongation of the jetties will become necessary." This statement afforded a remarkable confirmation of the conclusions he had arrived at from a careful study of the yearly charts.

Mr. Luiggi's remark that "it was assumed that the bars formed at river-mouths were produced mainly by the materials deposited by the river itself," could only apply to the descriptions of delta-forming rivers, in which cases the assumption appeared to be justified. In all the other rivers described, the influence of the waves in forming the bars, and the silting up of estuaries by alluvium brought in by the flood-tide, had been very definitely stated. Under the term littoral currents, he included the currents and waves produced by winds, as well as ocean and tidal currents.

He fully agreed with Mr. Caland that the Maas could not be accepted as an instance of an estuary with a narrow neck, as it had been trained in a funnel-shaped form. Moreover, at a very recent visit he had made to the Maas outlet, he had ascertained

Mr. Vernon-Harcourt.

that the travel of the sand there was mainly from the south, and not from the north as stated by Mr. Partiot, that the groynes along the coast to the north had been constructed merely to prevent the erosion of the coast, and that the bar at the mouth had been removed by suction-dredgers. The present depth of the outlet-channel, and the marvellous development of the maritime trade of Rotterdam, which he himself had witnessed, within the last fifteen years, did not bear out the gloomy views of Mr. Siccama. Mr. Stierle had given an interesting description of improvements at the outlets of several rivers on the east coast of North America, showing the value of dredging aided in some measure by training-works. The checking of the flood-tide at the mouth of the Adour mentioned in his Paper, to which Mr. Eyriaud des Vergnes demurred, had been gathered from the tidal rises of the Adour given in "Ports Maritimes de la France," and from the very definite statement made by Mr. Pettit with reference to this subject in the correspondence on "Harbours and Estuaries on Sandy Coasts,"[1] in 1882. He had, however, very recently been informed by Mr. Belleville, the present engineer of the Adour, that the tidal data given in the "Ports Maritimes" had been lately found to be incorrect. He understood that the closing of the openings in the jetties, and the lowering of the bar outside the Adour jetties by suction-dredgers, specially designed for such an exposed situation, had been determined on. Mr. Evaristo de Churruca had supplemented the description of the River Nervion in his Paper by some valuable particulars. He had been acquainted with the Ribble estuary, to which Mr. A. F. Fowler had referred, for a number of years, and had inspected it under various conditions of wind and tide. In traversing the extensive sands of the estuary at low water of spring-tides during a high wind, he had never seen any appreciable transport of the sand by the wind, as the sand had not time to dry sufficiently, especially as it was intersected by numerous rills. The observations of Mr. Fowler appeared to relate to the northern foreshore, where, no doubt, the sand was dry enough near high-water mark to be blown inland; and generalizing from this, Mr. Fowler had been led to an exaggerated notion of the drift of sand under the influence of wind alone. If sand was thus blown across the estuary from the south-west, it would gradually fill up the present trained channel, which would thereby be more injuriously affected than a south-western outlet.

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[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 69.

Mr. Vernon-Harcourt.

Professor Gaudard had proposed to reconcile the conflicting views expressed in the Papers with reference to the most satisfactory method of improving the outlet-channel of the Seine, by barring the central outlet between the Amfard and Ratier banks, and providing two outlet-channels, along the northern and the southern shore of the estuary respectively; but he (Mr. Vernon-Harcourt) feared that this solution would not satisfy either Author, and considered that the formation of two navigable outlets would be prejudicial to the depth and maintenance of both, and was at variance with the true principles of improvement of tidal rivers, which should aim at concentrating the tidal scour and fresh-water discharge into a single channel. Mr. de Coene had misconstrued his opinion with reference to converging training-walls in Liverpool Bay, in supposing that he considered "that these converging walls would certainly be preferable." To bear this out, Mr. de Coene had quoted a passage from his Paper on "Investigations into the Effects of Training-Walls in an Estuary like the Mersey," and had omitted a qualifying paragraph which immediately followed the quotation. This paragraph was as follows:—"Moreover, the comparatively narrow entrance over the bar, whilst deepening the bar channel, would check the tidal flow in the 'narrows' and upper estuary, which would affect the outer channel between the 'narrows' and the bar." He had been informed recently by the engineers in charge of the Seine model at Rouen, that, contrary to the statement of Mr. de Coene's, the Rouen experiments, like his own, had given unfavourable results with schemes providing a narrow outlet. Mr. Mengin-Lecreulx seemed to apprehend that the authority of the Institution would be invoked in favour of the scheme which Mr. Partiot's Paper appeared to have been written to promote. The appreciation, however, of the literary merit and trouble in preparing the Paper, extended by the Institution to a foreign engineer of high standing, did not in any way imply the slightest agreement with the views expressed in the Paper; and it would be wholly at variance with the scientific objects of the Institution if this act of courtesy could be used as a means of pushing forward a scheme which had been viewed with distrust by the several eminent engineers who had successively had charge of the tidal Seine. He was in agreement generally with the objections raised by Mr. Mengin-Lecreulx, Baron Quinette de Rochemont, and Mr. Vauthier, to the conversion of the outlet of the Seine into a narrow neck; and he was of opinion that, under the special conditions of the Seine estuary, the contraction of the outlet of the Seine by a breakwater from Villerville to Amfard

Mr. Vernon-Harcourt. would reduce the tidal rise inside, and would result in the silting up of the estuary, the formation of a bar outside, and a large advance of the foreshore in front of Trouville.

Mr. Partiot. Mr. H. L. PARTIOT,[1] in reply to the correspondence, observed that it was desirable to define the meaning of the term "neck," for Mr. Shoolbred had said that, "the contraction of the Seine between Tancarville and Quillebeuf had quite as marked, and a similar effect upon the tidal flow in that river, as the one between Royan and Pointe de Grave had upon that of the Gironde." The Pointe de Grave, however, which projected like a groyne towards the opposite shore, reduced the width of the Gironde to 3 miles, which amounted to 6½ miles at Richard and down to within a very short distance above the Point. On the Seine, on the contrary, Tancarville was 3 miles below Quillebeuf; and previously to the training-works, the opposite bank was 2½ miles from Tancarville, and about 1¼ mile from Quillebeuf; and the estuary from Havre to near Aizier appeared to him distinctly trumpet-shaped. The two estuaries acted in a totally different manner. He considered that an estuary had a neck when the two banks formed a decided contraction opposite, or nearly opposite one another, as on the Gironde, with a great enlargement in width above and below. This neck might be long, as on the Tagus below Lisbon, or short, as at the Pointe de Grave and on the Foyle. This definition would exclude rivers with trumpet-shaped mouths flowing into bays. He thought that the explanations he had given in his Paper concerning estuaries with necks would meet some of the objections raised in the correspondence. The depth in a neck depended on its width, and the quantity of water flowing through it. When the tides were small, or the neck too wide, the depth was less, and the lengths of the resulting channels below and above the neck were consequently shorter; and therefore it was not surprising that necks, either natural, or formed by training-walls, might have an insufficient depth, and form short and shallow channels. By deepening the neck, the channels formed by it would be deepened, and the bar below the neck would be lowered; and it was with the object of thus lowering the bar of the Loire that he had proposed to rectify and contract the oblique neck which separated St. Nazaire from Mindin Point, as referred to by

[1] Want of space has obliged the Editor to curtail this reply, which is an abridged translation of the MS. furnished by Mr. Partiot. The French original may be consulted at the Institution by any person desiring fuller details.—SEC. INST. C.E.

Mr. Vernon-Harcourt in the discussion. The effect, however, of the neck on the bar would be reduced if secondary channels came into the main channel between the neck and the bar; and therefore it would be advantageous to close these secondary channels, in order to extend the influence of the neck and the principal channel. Consequently it might be advisable to close the minor channels which opened on the left bank into the main channel of the Mersey below the neck. His theory was independent of the length of the neck, as proved by the case of the Tagus; and the bar might therefore be brought under the influence of the neck, and lowered, by prolonging the neck seawards by means of jetties. Mr. Partiot.

It was considered by Professor Gaudard that it would be better to make some of the flood-tide enter the Seine estuary over a low breakwater connecting Ratier and Amfard, in order that the water might come in less charged with sediment than at present; but he (Mr. Partiot) was of opinion that the tidal water might be admitted through the neck itself, as occurred in nature in the estuaries he had cited, which had existed since the earliest times without their being silted up. The tide carried out as much silt as it brought in, and more when aided by the fresh-water discharge of a river, as evidenced by the estuary of the Gironde, which had existed for centuries in spite of the materials brought down by the Garonne and the Dordogne. In Professor Gaudard's project for the Seine, the Villerville channel would admit a current fully charged with silty sand from the coasts of Calvados, nearly the sole source of the deposits which encumbered the estuary; and the navigation by this outlet would be impeded by the banks of Trouville and the Seine. It would be much better to close this outlet, and to admit, as far as possible, only the clear waters of the Antifer current into the estuary. Mr. Shoolbred had been imperfectly informed as to the proposals for securing the approaches to Havre, and the completion of the Seine training-works, which had not yet been passed by the Senate and must return to the Chamber of Deputies. The silting-up, however, which always had occurred in front of Havre when the navigable channel of the Seine remained in the centre, or at the south of the estuary, showed that the execution of the scheme of training-works approved by Mr. Shoolbred, would result in the accretion of the foreshore in front of Havre, behind the north training-wall; and even if the opening up of the Port of Rouen for the largest vessels should render the formation of the proposed new works on this site unnecessary, it would be essential to create and maintain a great depth in front of the existing

Mr. Partiot. entrance to Havre; and therefore he could not support the scheme referred to by Mr. Shoolbred.

When he had had charge, as engineer, of the works at the outlet of the Seine for four years, in 1857, the training-walls being nearly finished down to Tancarville and La Roque, he had to present a scheme for the extension of the training-walls, in compliance with the request of the town of Rouen, which desired their prolongation down to Honfleur. He, however, soon recognised that the fears of silting-up manifested at Havre would be well founded if this project was carried out, and that the entrance of the Seine should be fixed close to the jetties of this port. For that, it would suffice to prolong the left training-wall, transforming it into a breakwater carried out in front of Havre, in this way converting the estuary into a great sluicing-basin which would deepen the approach to the port. The estuaries of Arcachon and the Gironde showed that great depths would be obtained in front of Havre; that channels would be scoured out above and below, on the one side towards the trained river, and on the other side towards the deep sea near Havre; and that the Seine estuary, being converted into an estuary with a neck, would be maintained like this class of estuary. This was the basis of his project of 1859. Subsequently, for the sake of economy, and in order to increase the area of the enclosed estuary, the length of the breakwater was reduced by making it start from Villerville, thereby constituting it a Pointe de Grave at the mouth of the Seine. He had also designed a low training-wall along the left bank, to direct the current from Honfleur to the breakwater; and he had recently added a little branch channel going from the Seine near Tancarville through the northern part of the estuary, *Fig. 1.* The essential portion of the scheme, however, consisting in closing the southern and central channels, and making all the discharge of the Seine and estuary go through the northern channel close to the jetties of Havre, had been kept unaltered. It was necessary at the outset to determine the requisite widths between the training-walls below Tancarville, which depended on the discharge of the river at the various points and the desired depth, which he had arrived at by the methods he had indicated in 1861, and had developed in 1892.[1] The width of the river was at present 1,480 feet at Quillebeuf, and 2,300 feet at Tancarville; and adopting the

[1] "Étude sur le mouvement des Marées dans la partie maritime des Fleuves, 1861," and "Étude sur les Rivières à Marée et les Estuaires, 1892." H. L. Partiot.

Mr. Partiot.

widths proposed by the engineers of the Seine for the trained channel, of 3,940 feet at the mouth of the river Rille, and 4,600 feet opposite Honfleur, he had calculated that, with an average velocity of 3 feet per second, these widths would give depths of 10½, and 18⅘ feet below zero respectively at these places. As he considered it expedient that, in order to provide a roadstead for the largest vessels, a depth of 34½ feet below low-water of spring-tides should be afforded half-way between Honfleur and Havre, a depth of 46 feet was required in the channel near Havre, equivalent to that of the pass by which the flood-tide from the north entered the estuary in the neighbourhood of Havre. Assuming that the Seine was trained down to Havre, and adopting a mean velocity of 3¼ feet per second, equal to the flood-tide current in the Gironde at the Pointe de Grave, he had found that the width of the Seine at Havre should be 2,810 feet. The corresponding sections at the mouth of the Rille, Honfleur, and Havre respectively, would be 10,436, 14,857, and 17,344 square yards, and the discharges of the flood-tide at the same points, 271,392, and 505 million cubic yards respectively. The Seine thus trained down to Havre would, accordingly, furnish increasing sections below Tancarville; its outlet would directly face the tidal wave, and the clear current coming from Cape Antifer; and it would be placed as far as possible from the Calvados coast, the source of almost all the deposit in the estuary. This scheme, therefore, he thought ought to satisfy those who desired to have trumpet-shaped outlets. A depth of 10½ feet below zero, above the mouth of the Rille, would afford depths at high-water, of 36¼ feet at springs, and 30⅔ feet at neaps; and these depths would be maintained by the action of the currents alone, without dredging. Even if the estuary of the Seine was to be entirely silted up, the river might still be brought into the condition described; and the project offered perfect security in respect to it. The estuary, however, would not silt up; and new and important advantages could be derived from it. To facilitate the maintenance of the estuary, he proposed to reduce the width of the Seine a little at the mouth of the Rille and Tancarville, and to form an opening near the latter place, 262 feet wide, with its sill 3¼ feet below low-water, thereby creating a false branch, which by its probable wanderings, would undermine and keep down the level of the banks in the estuary, or if it maintained its direction, would produce the effects mentioned by Mr. Stoney with reference to the proposed training-works in the Mersey, namely, the lowering of the estuary for considerable distances on each side; and the sand stirred up by the tides and waves would descend into

Mr. Partiot. the false branch, and be carried away seawards, *Fig. 16*. The volume of water retained at spring-tides in the portion of the estuary to the north of the training-wall on the right bank, had been estimated from the chart of 1880 at 720,000,000 cubic yards; and adding to this the flow in the main channel during flood-tide given above, it appeared that 1,225,000,000 cubic yards should pass in through the neck during the flood, which, with an average velocity of 3½ feet per second and six hours fifty-nine minutes' duration of flow, would require a section of 44,764 square yards below mean sea-level at Havre, and a total width of 6,850 feet. In this estuary with a neck there would be two channels, one going into the main channel and the other towards Tancarville; and the channels would have a great depth near Havre, and would form a roadstead to the south and close to the port. A channel

Fig. 16.

Mr. Partiot's Scheme for the Seine, showing Anticipated Results.

2,300 feet wide and 33 feet deep would be made, giving Havre an outlet to the north through the little roadstead, which would be protected by a prolongation of the breakwater over the shoals of this roadstead; and an opening would be left in the breakwater to the south-west of the Havre entrance, 3,937 feet wide, in the neighbourhood of depths of 46 feet in the Amfard channel, so that Havre would be accessible at all times by channels at least 33 feet deep, *Fig. 16*. He had not taken into account the 114,000,000 cubic yards of water which covered the triangular area between the breakwater and Honfleur at spring-tides (which area would be kept low near the low training-wall by the effects alluded to by Mr. Stoney), because accretions had taken place since his calculations of the tidal capacity of the estuary had been made, and further accretions might occur before the completion of the works. The formation

of a triangular bank on the left shore, similar to Tuns bank at the mouth of the Foyle, Fig. 15, Plate 4, must be anticipated. The meeting of the two tidal waves from the north and east in the Bay of the Seine, maintaining high water at Havre and along the Calvados coast, was a wide-spread tidal phenomenon which could not be much affected by the closure of the two passes of the Seine; but it was probable that a portion of the Calvados wave, entering the bay along the coast towards Honfleur, would reach Havre earlier and prolong somewhat the period of high-water. This scheme, affording a depth of over 30 feet at high-water of neap-tides up to Rouen, a sheltered roadstead for the largest vessels near Havre, and two approach channels with depths of 33 feet at low tide rendering Havre accessible at all times, would cost £4,000,000, which would be promptly repaid by the saving effected in the cost of transport. These results explained why he could not accept the projects prepared by the Commission of 1885, or subsequently under its inspiration. Mr. de Coene had stated that the experiments made at Rouen with a little model, similar to the one employed by Mr. Vernon-Harcourt, had convinced him that the formation of the proposed neck at the mouth of the Seine would give depths of 23 feet at low-tide from Tancarville to the outlet. He (Mr. Partiot) joined with those who urged the continuation of these experiments and their publication. Mr. Partiot.

Though Mr. Mengin-Lecreulx was struck with the expenditure which this project would involve, he had arrived at his estimate of £4,000,000, to a great extent, from the cost of the Boulogne breakwater, and of the Seine training-walls; and of this sum, £2,560,000 would suffice for the works above Havre, the remainder being required for the detached breakwater facing Havre, and for completing the northern channel. Great economy, moreover, might be effected by adopting the system of construction employed by the Dutch, who were about to close the entrance to the Zuider Zee.

Both Mr. Mengin-Lecreulx and Mr. Vauthier had strongly insisted that the construction of the neck would lower the level of high-water in the estuary and above; but the neck at the Pointe de Grave did not prevent high-water attaining the same level in the Gironde, and up to Bordeaux in the Garonne, as at Royan, and in the Foyle, the tide rose higher at Moville above the neck than at Warrenpoint below. Moreover, in these two estuaries, the tide fell again directly after high-water; whereas, at Havre, high-water lasted for over two hours, facilitating the filling of the estuary. Observation was therefore opposed to this objection. Though the section, moreover, of the mouth of the Seine from

Mr. Partiot. Havre to Villerville, with a length of 30,840 feet, and an average depth of $21\frac{2}{3}$ feet, amounted to 69,255 square yards, as compared with 44,764 square yards at the neck, yet the greater depth of $58\frac{4}{5}$ feet at mean sea-level in the neck would render the section through the neck capable of discharging slightly more, with the same average slope, than the other. The tidal wave also would be propagated more easily through the new entrance than at present, since the rate of propagation, according to Lagrange's formula, was proportional to the square root of the depth, and in the neck would be $1 \cdot 69$ times its present rate.

In calculating the loss of height of high-water in the estuary, Mr. Vauthier had supposed that the loss in the neck at any given time was proportional to the square of the height of the water above low-water; but De Prony's formula of discharge showed that the height of the water must be reckoned from the bottom, and not from low-water. Observation proved that the loss of height of high-water was generally nothing in estuaries, and that the tides passed easily through necks, as explained by the foregoing reasons, and would be the same for the Seine, and, therefore, he need not discuss Mr. Vauthier's calculations.

It had been asked by Mr. Mengin-Lecreulx what would happen during the execution of the works. Mr. Partiot believed that it would depend on the way in which they were carried out. He considered that they should be begun by the Villerville breakwater, as recommended by Mr. Caland, as the inner works would thus be executed much more easily and cheaply. In commencing the breakwater at Villerville by closing the south channel, and by beginning the foundations of the breakwater in the middle channel, the outlet channel would go to the north of the Amfard bank as it had done several times; and when, in March 1893, it had taken the course which he desired to give it, the Chamber of Commerce of Rouen ascertained that it was in a good condition. Inside the estuary, directly the opening at Tancarville had been made, the northern training-wall should be prolonged, to prevent the channel from going away from Honfleur. The low training-wall on the left bank beyond Honfleur would be constructed towards the close of the works, when silting-up had begun in the triangle between the breakwater and Honfleur.

Though there was no bar in the channel penetrating the estuary between the Amfard and Ratier banks, it might be said that the sands of the estuary discharged by the neck would create a bar at the mouth of the Seine. This bar, however, would be formed like that of the Rhone; but the neck being connected with the central

channel, it was certain that the bar would be formed at the extremity of this channel, in the depths of 60 feet below zero which were found near Havre. The bar of the Mersey was $9\frac{1}{3}$ miles beyond the neck, and the bar of the Gironde 15 miles from the Pointe de Grave. Small-scale models might give useful indications on this point; and Mr. De Coene had mentioned that the Rouen model had shown a depth of 26 feet over the bar. In any case, he believed that the Antifer current would drive the sands on to the Seine bank, and that the bar would eventually disappear. Mr. Partiot.

According to Mr. Mengin-Lecreulx the opinion of French engineers was opposed to the scheme; but Mr. Partiot had received very different assurances; and the erroneous views of the Commission of 1885, the resulting obligations, and the situation of the government in France, must be taken into account. Mr. Mengin-Lecreulx had declared that the Seine possessed a neck, and that it had only a limited depth; but no neck was now visible in the Seine which flowed into its estuary through a gradually widening channel. He had also added that the navigation of the Gironde was beginning to meet with difficulties; these did not, however, arise from the neck, whose influence ceased $12\frac{1}{2}$ miles above, but from the changes of the channels in the upper part of the estuary, and of the two large rivers which flowed into it. The existence of a neck was evidently not a remedy for every evil, but if the present condition of Havre was compared with the results hoped for from the proposed scheme, it was clear that this port would be far from suffering any loss. Though Mr. Mengin-Lecreulx considered that the approaches to Havre would be encumbered by the deposit of sands coming from the Seine bank and the estuary, nevertheless, when this port was given two approaches and depths of 33 feet at its entrance, no dangerous bar would be formed in the north channel; the bar in the south-west channel could be lowered by dredging, and the Antifer current would eventually disperse it. The government desired to achieve success with two separate projects for Rouen and Havre, in spite of the natural connection between the fixing of the channel in the middle of the estuary and the silting up of the ports of Honfleur and Havre; and he could not approve of the adoption of such a course.

It was urged by Baron Quinette de Rochemont that rivers might be cited as being with or without a neck, according to the theory it was desired to establish, and denied that the Foyle was comparable to the improved Seine. The chart, however, of the Foyle reproduced almost precisely, when viewed on the reverse

Mr. Partiot. side of a tracing, the main features of the Seine scheme as carried out by nature, as well as the details of the surroundings, such as the rivers Touques and Rille, Fig. 15, Plate 4, and *Fig. 16*. The waters of the Foyle were clear, whilst the Seine also brought very little silt down during floods. The north winds which caused the travel of the sands along the coast, directed them near the Foyle, and also the mouth of the Bann towards the west, just as the north-west winds in the channel pushed them eastwards near the Seine, and turned the outlet channel of the river Touques in the same direction. The flood-tide coming from the north-east at the entrance to the Foyle could not bring much sand into the estuary on account of the neck which protected it; and the reverse current which, after flowing into the Seine estuary near Villerville, returned charged with alluvium in front of Havre, would not be able to effect this circuit if the southern and central passes were closed; and the sands from the Calvados coast would be arrested by the triangular bank which would be formed on the left bank of the channel beyond the neck, *Fig. 16*, just as the sands which came from the river Bann accumulated on the bank of Tuns, Fig. 15, Plate 4. The current from Cape Inishowen followed the coast, like the current from Cape Antifer; and the littoral current of the Bann was opposed in direction to the other, like the current along the Calvados coast.

The fact was recalled by Mr. Vauthier that the range of tides at the mouth of the Foyle was much smaller than at the Seine outlet; but the only conclusion to be drawn was, that if a rise of $7\frac{2}{3}$ feet at springs gave good results on the Foyle, a rise of $23\frac{3}{5}$ feet would give still better ones. Baron Quinette de Rochemont said that the Villerville breakwater would change the regime of the currents of the estuary; but if this regime was bad, there should be no more hesitation about modifying it than in the case of a sick man to cure him. He (Mr. Partiot) had explained what the new regime at the entrance to Havre would be; and he could not see how the second high-water, which was a purely marine phenomenon, and which reached Havre in following the coast of Antifer, could cease to be produced. The port of Trouville would retain approximately its present condition, for the travelling sands from the Calvados coast would continue their course along the shore near the breakwater until arrested by the triangular bank below the neck, just as the river Bann had not been silted up by the sand travelling along the coast towards Macgilligan Point, which accumulated at Tuns bank. The deposits which had taken place within the last few years in the Seine estuary were partly due to the displacement of

the banks in it; but they must also be attributed to the great Mr. Partiot. width ($5\frac{3}{8}$ miles) of the mouth, all along which the flood-tide could bring in the sands, which the ebb, dispersed over this wide outlet, was powerless to drive out to sea. Trumpet-shaped estuaries were silted up when the channel became fixed, and this had been the effect of the training-works down to the mouth of the Rille; but the same was not the case in estuaries protected by a contracted outlet; and it was to be regretted that the works in the Seine estuary were not commenced by the construction of the Villerville breakwater. Experiments with small-scale models might give different results according to the manner in which they were worked; and he would urge the continuation of the Rouen experiments, which might furnish very different conclusions to those drawn from them by Baron Quinette de Rochemont. Mr. Vauthier considered that the differences in each outlet involved a separate problem for each, and did not take into account that nature acted in accordance with general laws, which were essential to know, and which might often be utilized. He said that the system of necks might be advantageously used within certain limits for tideless rivers; and he (Mr. Partiot) agreed with him that, when such a river dispersed its waters over a great width at its outlet, it might be useful to concentrate them in a single point, which was effected by closing the secondary branches of a delta. Mr. Vauthier, however, found it difficult to understand the advantage of introducing a large quantity of tidal water into an estuary or a river through a neck, in order thereby to obtain an improvement; but the greater the volume of water which entered, the greater and deeper should the channels become. Observation showed that when the volume of tidal water introduced was diminished the depth soon decreased and estuaries silted up, and that it was most essential to avoid as much as possible the reduction of the tidal water. Mr. Vauthier, in criticising the proposed scheme for the Seine, had stated that the training-walls were to be prolonged without increasing the widths of the river; but it had been shown by the case of the Gironde that the essential point was for the sections, and especially the discharges, to increase seawards, and that these conditions were fulfilled in the arrangements of the scheme. He did not question the importance of the range of tide, about which Mr. Vauthier was so much concerned; but the laws of nature which he had pointed out applied to little ranges as well as great; and the limit of 13 feet, chosen by Mr. Vauthier, was neither fixed nor justified. A reduction in the width of the neck by the travel of the sands, as in the case of the

Mr. Partiot. Foyle, might produce depths greater than proportionate to the range of tide; for, whereas the Gironde at the Pointe de Grave, with a rise of tide of 17⅞ feet and a width of 5,300 yards, had a depth of about 100 feet, the Foyle with a rise of tide of only 7⅞ feet, but with a width in the neck of only 1,475 feet, attained a depth of nearly 70 feet. Mr. Vauthier had objected to the examples cited, commencing with the Foyle, and had dwelt on the inconveniences they exhibited in spite of the existence of a neck. He (Mr. Partiot) did not pretend that this condition exempted them from all defects; and he had confined himself to deducing from these examples, that necks produced great depths in the necks themselves, and channels above and below. He had taken account in his formulas of the discharges of the rivers, as well as the range of the tides; and he did not think that a classification based upon these ranges could prove that the natural laws he had indicated were inexact, as Mr. Vauthier supposed.

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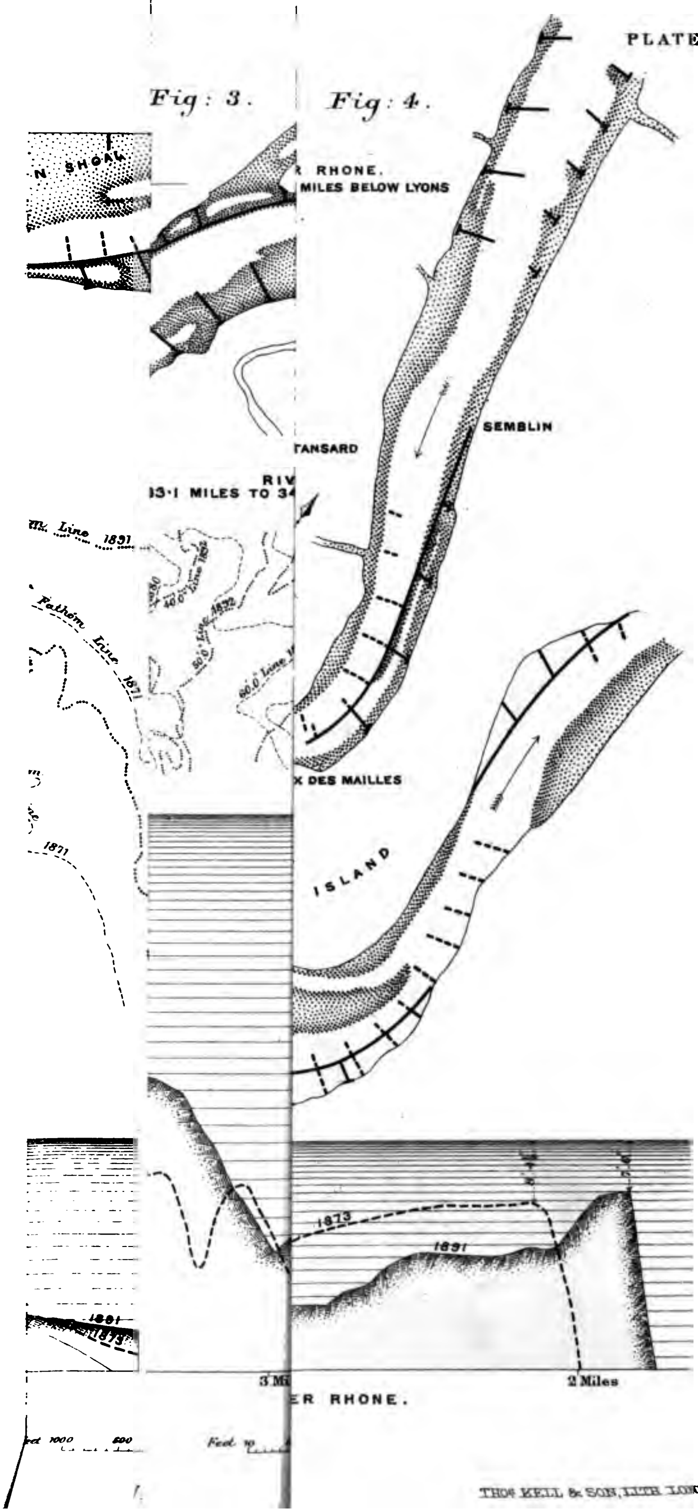
24 April, 1894.

ALFRED GILES, President,
in the Chair.

The discussion upon the Papers on "The Training of Rivers," by Mr. Vernon-Harcourt, and on "Estuaries," by Mr. Partiot, occupied the evening.

Fig: 3. Fig: 4.



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